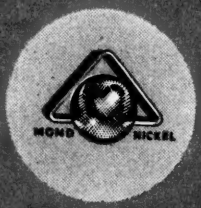
THE NICKEL BULLETIN

Monthly Abstracts of Recent Literature

DECEMBER

1960 Volume 33 No. 12



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SUBJECT AND AUTHOR INDEXES

The subject and author indexes to Volume 33 of *The Nickel Bulletin* are in process of preparation, and will be distributed to readers with the January issue of Volume 34.

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ABSTRACTS OF CURRENT PUBLISHED INFORMATION ON NICKEL AND ITS ALLOYS

GENERAL

Standard Designations of Alloys and Steels Used in Aeronautical Applications

J. J. VAGI: 'Standard Designations of Alloys for Aircraft and Missiles.'

Defense Metals Information Center, Battelle Memorial Institute, Memorandum 42, Jan. 25, 1960; 68 pp.

This memorandum was prepared as an aid to the classification of information on steels and alloys used in aeronautical and missile applications.

It comprises four tables. Table 1, *Trade Designations*, takes up 28 pages of the publication. In the first column are listed, in alphabetical order according to tradename, all relevant steels and alloys (many nickel-containing) commercially available to date of compilation. In other columns reference is made to the designations of specifications issued by the Military, American Iron and Steel Institute, Society of Automotive Engineers, and the American Society for Testing Materials. The manufacturer and probable patentee are noted, and the nominal composition of each material covered is included in the table.

In Table 2, *Aeronautical Material Specifications*, the author has listed the specifications pertinent to heat- and corrosion-resisting alloys and steels and correlated them with A.I.S.I., S.A.E., and trade designations. The forms in which the materials are supplied are alluded to.

Table 3, *Standard Designations for Hot-Work Tool Steels*, contains the A.I.S.I. and trade designations for hot-work tool steels.

A.I.S.I., Military, S.A.E., A.M.S. and A.S.T.M. designations for selected high-strength and heat- and corrosion-resisting steels (including nickel-containing low-alloy and stainless steels) are collated in Table 4.

NICKEL

Production, Analysis and Properties of Ultra-Pure Nickel

G. H. MORRISON, L. S. CASTLEMAN and H. W. HEES: 'Study of the Properties of Ultra-Pure Nickel. Scientific Report No. 1, Jan. 1, 1959-Sept. 30, 1959.'

*Airforce Cambridge Research Center, Report TR*59-104-205-704-3, Dec. 15, 1959; 30 pp.+ appendix.

The interaction between electron-emitting oxides, the nickel substrate and the impurities present in the nickel has long been the subject of investigation in connexion with the rôle of nickel in thermionic emission from oxide cathodes. Information on the oxide cathode can be obtained using materials of known composition (e.g., of ultra-high purity) and controlling their interactions *in vacuo*, and, in the research discussed by the authors, it is proposed to develop an experimental diode which (involving use of extremely pure nickel) will minimize migration of impurities into the cathode. The test programme was initiated with a dual aim: (1) to study the thermionic properties of alkaline-earth emitters applied to an ultra-pure-nickel base, and (2) to investigate the physical and chemical properties of pure grades of nickel. Before any work could be carried out in this connexion, it was first necessary (*a*) to develop methods for the preparation, on a laboratory scale, of ultra-pure nickel, (*b*) to establish analytical techniques with the sensitivity requisite for determination of trace impurities in such nickel (and, thereby, for assessing the efficacy of the various purification processes studied), and (*c*) to devise fabricating, processing and test procedures which would obviate the risk of the nickel's becoming contaminated. The work carried out to achieve these three aims forms the subject of the present interim report.

The feasibility of using floating-zone refining as a technique for preparation of ultra-high-purity nickel is being studied within the scope of phase (*a*). Results to date indicate that, during zone refining, purification of compacted carbonyl-nickel powder (supplied by The Mond Nickel Company, Ltd., and selected as the most pure grade commercially available) takes place mainly by evaporation of materials of higher volatility. This purification process does not, however, extend to iron and silicon, though there is some evidence, supported by *a priori* considerations, that the silicon may eventually be zone-refined with the development of more effective apparatus; efforts are being made to extract the iron chemically. The floating-zone technique is regarded as an excellent method of melting nickel without risk of contamination from a crucible, and can therefore be employed to consolidate the chemical extraction product and remove volatile impurities. A survey of chemical methods of purifying the nickel suggested that extraction and ion-exchange techniques are of promise in reducing the iron content, and zone refining or electrodeposition should eliminate some of the silicon.

Various analytical techniques were considered in connexion with phase (*b*). The work which culminated in the development of a rapid direct spectrographic method, stated to be two orders of magnitude

more sensitive than previous methods, is discussed, and the procedure itself is described (by R. L. RUPP, G. L. KLECAK and G. H. MORRISON) in an appendix to the report.*

In the development of a test diode suitable for evaluating the thermionic properties of ultra-high-purity nickel (the design of such a diode is now virtually completed), the most important requirement, apart from satisfactory electrical characteristics, was considered to be a rigidly controlled environment, and stringent limitations had to be imposed on the materials and processing techniques used. In studies of processing techniques, major emphasis was placed on avoiding contamination, and the following factors are discussed in this respect: fabrication of deep-drawn cups without appreciable pick-up of impurities; elimination of 'Pyroceram' frit-sealing techniques for final closure (due to contamination of the cathode); elimination of the use of alumina-coated heaters (because of major cathode contamination); and the design and construction of a suitable ion-pumping vacuum system to eliminate oil contamination. A micro-second pulser and an interface bridge have been set up.

Adherence of Oxides on Nickel and Other Metals

R. F. TYLECOTE: 'Factors Influencing the Adherence of Oxides on Metals.'

Jnl. Iron and Steel Inst., 1960, vol. 196, Oct., pp. 135-41.

A review of the literature on adherence of oxides to metals† having indicated that more information was required on the mechanical properties of the oxides at elevated temperatures (particularly on their capacity for deformation, the relevant expansion coefficient of metal and oxide, and the effect of the compressive stresses at the base of the oxide film), the study now reported was initiated in an attempt to evaluate the adherence of oxide films as a function of these properties.

The study comprised three phases:

(1) A general investigation was made of the adherence of oxide films on high-purity nickel, cobalt, electrolytic chromium, and grades of iron differing in purity.

(2) Previous work had shown cuprous oxide to exhibit a strength of 1-2 tons/in.^{2} (1·5-3 kg./mm.^{2}: 2240-4480 p.s.i.) and an elongation of up to 20 per cent. in the range 400°-800°C. Such properties were thought to be sufficient to explain the relative adherence of oxide films on copper, despite the large difference in the coefficient of expansion of metal and oxide. Since nickel oxide is readily adherent, and since iron oxides are generally non-adherent, it was decided to determine the strength of nickel oxide, α Fe_2O_3 and wüstite at high temperatures.

(3) The coefficients of expansion of FeO, Fe_2O_3, NiO, CoO, Co_3O_4, Cr_2O_3, Cu_2O and CuO were compared with those of the parent metals.

The main point arising from phase (1) is considered to be the extraordinary adherence of the oxide film on nickel. Although the purity was of the same order as low-manganese 'Remco' iron, the adherence was very different, suggesting either that the mechanical properties of the oxides must differ greatly or that a 'keying-on' effect is important.

In phase (2) of the study, the strength of nickel oxide was found to reach a maximum of 9300 lb./in.^{2} at 900°C., while that of α Fe_2O_3 was maximal (5000 lb./in.^{2}) at 1100°C. The ultimate tensile strength of wüstite was much lower than that of the other oxides: it was sensitive to loading rate, creep effects were observed, and in no case was a measurable elongation attained.

The negligible difference between the coefficient of thermal expansion of nickel and nickel oxide is thought to explain the extremely good adherence of films on nickel after cooling to room temperature.

Diffusion Spectrum of Nickel Carbonyl in Solution and in the Liquid State

M. BIGORGNE: 'Study of the Diffusion Spectrum of Nickel Carbonyl in the Liquid State and in Solution.'

Comptes Rendus, 1960, vol. 251, July 18, pp. 355-7.

The author's study of the diffusion spectrum o nickel carbonyl (1) in the liquid state at −28°C., and (2) in solution in pentane at −55°C., revealed three new bands, in addition to those already known. The origins of these bands are discussed.

See also

Diffusion Spectrum of Nickel Carbonyl in the Gaseous State

M. BIGORGNE and A. CHELKOWSKI: 'Study of the Diffusion Spectrum of Gaseous Nickel Carbonyl.'

Comptes Rendus, 1960, vol. 251, July 25, pp. 538-40.

An investigation was made of the diffusion spectrum of gaseous nickel carbonyl at 30°C. and atmospheric pressure. The results of the study (presented in the present note) indicate that the frequencies of the C-O bonds are higher, and those of the Ni-C bonds lower, than those determined for the liquid state (*see previous abstract*).

Self-Diffusion of Iron in Nickel Ferrite

R. H. CONDIT, M. J. BRABERS and C. E. BIRCHENALL: 'Self-Diffusion of Iron in Nickel Ferrite.'

Trans. Metallurgical Soc., A.I.M.E., 1960, vol. 218, Aug., p. 768.

In the oxidation of pure iron at temperatures above 700°C., the overall rate is determined mainly by the rapid growth of wüstite, through which iron

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* Details of the technique have been published separately in *Analytical Chemistry*, 1960, vol. 32, July. pp. 931-3: see abstract in *Nickel Bulletin*, 1960, vol. 33, No. 11, pp. 271-2.

† See abstract in *Nickel Bulletin*, 1960, vol. 33, No. 11, p. 282.

ions can diffuse rapidly. Addition of nickel to the iron progressively decreases the stable range of composition of wüstite, and, at a nickel content sufficient to eliminate wüstite as a stable phase, the spinel becomes the fast-growing phase. The investigation reported in this note was undertaken to determine the validity of the hypothesis that substitution of nickel for iron in magnetite might decrease the rate of spinel growth by reducing the iron mobility.

The experiments were carried out on discs cut from nickel-ferrite boules (chemical analysis revealed an iron/nickel atomic ratio of 2·88). The data presented are regarded as demonstrating that substitution of nickel for a considerable part of the iron in magnetite substantially decreases the iron mobility. It is considered that nickel plays several rôles in reducing the oxidation rate of iron-nickel alloys: (1) it reduces progressively the stability range of wüstite; (2) it reduces progressively the stability range of the iron-nickel spinel phase in terms of the variation in cation to anion ratio; (3) it reduces the cation stability in the spinel phase (which is the faster-growing phase in the absence of wüstite.)

Symposium on Fuel Cells

'Fuel Cells.'
Edited by G. J. YOUNG.

Published by *Reinhold Publishing Corporation*, New York: *Chapman and Hall, Limited*, London: 1960; 154 pp. Price $4·75; 46/-.

The quest for new and improved energy converters has in recent years focused attention on the potential value of fuel cells in this respect, and the feasibility of developing types of cell which would eventually provide a practicable and economical means of direct energy conversion is being much studied. Within the last few years the subject has been considered at a few scientific meetings, and isolated papers have appeared in the technical press, but, until 1959, no attempt had been made either to organize a symposium which would include contributions from prominent scientists active in the field, or to publish a set of papers which would review in detail the present state of knowledge and development. In September 1959, however, the Gas and Fuel Division of the American Chemical Society took advantage of the 136th National Meeting in Atlantic City to hold a Symposium on Fuel Cells. This volume contains the papers read at the Symposium and includes a chapter summarizing the panel discussion that followed the papers' presentation. The work of some of the authors of the nine papers comprising the symposium has, the editor suggests, 'provided, in part, the impetus for the renewed activity in a field that had received only casual study for over a century'; the following list of the papers published in the present volume will give some idea of the comprehensiveness of the information given.

H. A. LIEBHAFSKY and D. L. DOUGLAS: 'Introduction', pp. 1-10.

K. KORDESCH: 'The Hydrogen-Oxygen (Air) Fuel Cell with Carbon Electrodes', pp. 11–22.

G. J. YOUNG and R. B. ROZELLE: 'Catalysis of Fuel-Cell Electrode Reactions', pp. 23–33.

L. G. AUSTIN: 'Electrode Kinetics of Low-Temperature Hydrogen-Oxygen Fuel Cells', pp. 34–50.

F. T. BACON: 'The High-Pressure Hydrogen-Oxygen Fuel Cell', pp. 51–77.

H. G. J. BROERS and J. A. A. KETELAAR: 'High-Temperature Fuel Cells', pp. 78–93.

H. H. CHAMBERS and A. D. S. TANTRAM: 'Carbonaceous Fuel Cells', pp. 94–108.

E. GORIN and H. L. RECHT: 'Nature of the Electrode Processes in Fuel Gas Cells', pp. 109–128.

D. L. DOUGLAS: 'Molten Alkali Carbonate Cells with Gas-Diffusion Electrodes', pp. 129–149.

ELECTRODEPOSITION AND OTHER COATING METHODS

Deposition of Nickel by Thermolysis of Nickel Carbonyl

L. W. OWEN: 'Vapour Deposition of Metals with Particular Reference to Nickel Plating by Thermolysis of Nickel Carbonyl.'

Trans. Inst. Metal Finishing, 1960, vol. 37, Autumn, pp. 104–7.

Vapour deposition (deposition of a metallic coating by thermal decomposition of a volatile compound of the appropriate metal) offers two important advantages: (1) it enables deposition of many metals which are difficult to deposit electrolytically; (2) it permits the production of metallic coatings on materials which cannot be electroplated. In the latter connexion, vapour deposition provides a means of applying nickel coatings onto metals which are difficult to deposit by wet methods, either due to their reactiveness towards the electrolyte (as in the case of magnesium and uranium) or because of the possibility of their retaining water (such as with porous metal compacts). The properties of the coatings obtained are comparable with those of electrodeposited nickel, and the nickel can be deposited to any thickness at rates greatly exceeding those commonly employed in electrodeposition.

Most vapour-deposition processes employ the halide or carbonyl of the metal as the volatile compound. In the case of nickel, use is made of the carbonyl since it is highly volatile, whereas the halide is thermally stable and non-volatile. The carbonyl process has much to recommend it, since, in contrast to methods involving halides, the use of carbonyls does not lead to attack on the basis metal, a factor of importance in determining adhesion and continuity of coating. Nickel has perhaps a great advantage over other metals like iron, molybdenum and tungsten, in that it is not embrittled by the co-deposition of small amounts of carbon. Nickel

is therefore in a unique position, since it is both volatile (i.e., its vapour is easily transportable) and not embrittled by co-deposited carbon. In addition, the plating temperature, under 250°C., is lower than that of almost any other vapour deposition process. Condensation in the equipment is easily avoided, and the thickness of the coating can be precisely controlled. Rates of deposition as fast as 30×10^{-3} in./hr. are achieved without difficulty.

In this paper the author gives details of the design and operation of low-pressure and atmospheric-pressure plant for nickel-carbonyl plating, and discusses the principal variables of the process. In the concluding section attention is drawn to the properties characteristic of such coatings.

Influence of Pre-Plating Procedures on the Porosity of Electrodeposits

M. CLARKE and S. C. BRITTON: 'The Influence of Pre-Plating Processes on the Porosity of Electrodeposits on Steel.'

Trans. Inst. Metal Finishing, 1960, vol. 37, Autumn, pp. 110–20.

Investigations of the influence of surface preparation on the properties of metallic coatings electrodeposited onto a steel substrate have given rise to somewhat conflicting results, a fact which the authors of the present paper attribute, in part, to the different methods used to assess porosity. In the study now described, use was therefore made of the electrochemical method of obtaining an index of the porosity of electrodeposits*, which, yielding a numerical value of known significance in a relatively short time, offers advantages for investigation of large numbers of specimens.

Five different grades of rolled steel, serving as basis metals, were subjected to a cleaning and preparation cycle, the eighth of the ten stages of which was varied to determine the effects, on the porosity of nickel, tin-nickel, speculum and tin electrodeposits, of including, in turn, each of the following treatments: chemical polishing, chemical smoothing, etching, electropolishing, mechanical polishing and anodic cleaning. Full details of these pre-treatments, and of the basis materials, plating solutions and procedures employed, are included in the paper.

It was found that the depth of steel removed by any method of pre-plating preparation had an influence on the porosity of the coating sufficiently large to obscure, if it were not controlled, the effects arising from the preparation method. The removal of the extreme surface layer of steel (about 0·00001 in.: 0·00025 mm.) influences the porosity of the applied coating, for better or worse, according to the metal deposited and the conditions of deposition. Evidence was obtained that this effect depends on the form of crystal growth of the deposit. With deeper uniform penetration into the steel, zones were reached which were apparently features of the steel and influenced porosity almost independently of the character of the deposit. These zones are attributed to bands of non-metallic inclusions. The observed effect of depth of preparation helps to explain the divergent results previously obtained in investigations of surface penetration. It is suggested that, in practice, when controlled penetration cannot be expected, no method of surface preparation will give consistent porosity in deposits on a range of steels. The response of an undercoating to the condition of the steel surface was found to govern the porosity of a composite coating: well-chosen undercoatings may therefore, it is suggested, offer the best method of obtaining consistent results and of reducing porosity.

* Details of the method were published by the authors in *Trans. Inst. Metal Finishing*, 1959, vol. 36, Pt. II, pp. 58-66: see abstract in *Nickel Bulletin*, 1959, vol. 32, No. 4, pp. 108-9. The test plate is made the anode under such conditions that current passes only *via* the electrolyte-filled pores. The change of potential at the surface of the test plate is measured as the applied current is increased. The slope of the line representing the relationship of the displacement of potential to current density averaged over the test plate, dV/dI, is regarded as a measure of the electrolytic resistance of the pore channels, and is thus an index of porosity.

Influence of Electroplating on the Fatigue Strength of the Substrate Material

R. A. F. HAMMOND and C. WILLIAMS: 'The Effect of Electroplating on Fatigue Strength.'

Metallurgical Reviews, 1960, vol. 5, No. 18, pp. 165–223.

Electrodeposited coatings play an important and expanding rôle in the engineering industries, and are used not only to confer corrosion protection, but also to restore worn or over-machined components to size ('building-up'), or to modify the surface properties of the component for some specific purpose (e.g., to increase the surface hardness and thereby promote wear-resistance). These engineering applications of electrodeposition are very largely confined to steel components, and, probably for this reason, there are relatively few references in the literature to the effects of plating on the mechanical properties of non-ferrous materials. For the most part, therefore, this review is concerned with the effect of electroplating on the fatigue strength of steel substrates.

In the case of chromium deposits, the subject is reviewed in sections covering the effects of the following factors: thickness of the deposit, the current density employed during plating, internal stress, post-plating baking treatment, strength of the substrate, shot-peening, grinding, nitriding. In reviewing information on the effects of nickel plating, the authors take account of the following variables: thickness of the deposit, internal stress, baking, strength of the substrate, shot-peening. Loss in fatigue strength as a result of cadmium or zinc plating is relatively unimportant, and the literature available, and presented, in this connexion is relatively scanty. Sections on hydrogen embrittlement, corrosion fatigue and the mechanism of fatigue failure in electroplated metals end the review.

The conclusions reached by the authors are quoted below:

'It appears that the fundamental limitation of the coatings used for engineering applications, viz., nickel and chromium, is their relatively low intrinsic fatigue strength relative to the high-strength steels to which they are frequently applied (aggravated by tensile internal stress). A need exists therefore for investigating the possibilities of electrodepositing stronger coatings. In the case of nickel, this is clearly feasible by the use of organic addition agents in the plating bath, which could have the added advantage of imparting compressive internal stress to the electrodeposit. The prospects of applying a similar remedy for chromium deposits are far less promising, however. The harmful effects of chromium plating can be alleviated at the cost of some reduction in hardness of the coating by high-temperature baking (~450°C.: 840°F.) for such steels as will permit heat-treatment at this temperature without loss of temper.

'When the elimination of loss in fatigue strength is of paramount importance, this may be achieved for all coating metals by inducing a sufficiently high intensity of internal compressive stress in the basis metal, e.g., by shot-peening or rolling before plating. When necessary, as, for example, in the case of closely fitting or running parts, the smoothness of the peened component may be restored by cautious grinding before plating. Moreover, components treated in this way may be baked at a low temperature after plating, to relieve hydrogen embrittlement without detriment to the fatigue strength. Relatively strong and ductile coatings, e.g., nickel, can be peened or rolled after plating with similar advantage.

'Finally, most fatigue tests have been carried out in air. The results obtained are probably indicative of the true performance of thick non-porous coatings, or of thin coatings operating under favourable corrosion conditions. However, while the performance of such coatings under severe corrosion conditions may be very much reduced, they will frequently provide a marked improvement in corrosion fatigue as compared with that of the unprotected steel under the same conditions.'

Corrosion Tests on Nickel-Plated Steels

E. RAUB, A. DISAM and G. SCHMIDT: 'Corrosion Tests on Nickel-Plated Plates of Killed and Rimmed Steel.'

Werkstoffe u. Korrosion, 1960, vol. 11, Sept., pp. 554–63.

In a previous investigation RAUB and his co-workers conducted atmospheric-corrosion tests to determine the influence, on the corrosion behaviour of matt-nickel coatings, of (1) the variables involved in the preliminary degreasing operation, (2) use of killed or rimmed steels for the basis metals, and (3) copper plating prior to deposition of the nickel coating.

The coatings evaluated were deposited on sheet cold-rolled from six grades of steel, two of which had been killed with silicon and one with aluminium. The remaining three were rimmed. Prior to plating, the specimens were anodically or cathodically degreased, at room temperature or 90°C., using a current density of 5 amp./dm.², in an electrolyte of the following composition: sodium hydroxide 60, sodium carbonate 30, g./L. The effects of the degreasing procedure were evaluated by varying the period and temperature at which the specimens were subjected to anodic or cathodic treatment. The specimens were exposed to atmospheric corrosion (in a location representative of a mild industrial town environment) in three conditions: matt-nickel-plated to an average thickness of 20μ without subsequent treatment; matt-nickel-plated and buffed; copper-plated and finally nickel-plated, both coatings being deposited to a thickness of 10μ and then buffed. The results of these atmospheric corrosion tests were reported in *Metalloberfläche*, 1959, vol. 13, Oct., pp. 330–6: see abstract in *Nickel Bulletin*, 1959, vol. 32, No. 12, pp. 352–3.

In the test programme now reported, these long-time atmospheric-exposure tests were complemented by laboratory corrosion tests on specimens of the same grade of steel subjected to the same pre-treatment procedures and nickel-plated under the same conditions as those used in the previous tests.

Buffing was, in general, found to have a beneficial effect on the corrosion-resistance of the 20μ matt-nickel deposit. The introduction of a copper coating was (in conjunction with subsequent buffing) also beneficial, but offered no advantage *vis-à-vis* the single-coat polished specimens.

The influence of the type of steel on the protection conferred by the deposits is considered of considerable interest. The killed or rimmed steels exhibited no characteristic differences in corrosion-resistance when nickel-plated under the same conditions. The scatter in the data was so great as to prevent determination of the small differences in behaviour observed in the atmospheric tests, and, in particular, the corrosion-resistance of aluminium-killed steel did not, in contrast to the findings of the latter investigation, differ from that of the other killed or rimmed steels.

Although the authors consider that no general conclusions can as yet be drawn from the test programme, they nevertheless regard the results as a refutation of the widely held opinion that nickel plating confers less corrosion protection on killed steel than on rimmed steel. The slightly higher silicon content of silicon-killed steel had no effect (particularly when the steel was given an undercoating of copper) on the corrosion-resistance of the nickel deposit. With regard to the nickel-plated aluminium-killed steel, further tests are deemed necessary to resolve the discrepancy between the results of the atmosphere and laboratory tests.

Resistance of Nickel-Plated Materials to Corrosion by Domestic Detergents

See abstract on p. 319.

Structural Stability of Tin-Nickel Electrodeposits

R. F. SMART and D. A. ROBINS: 'The Structural Stability of Tin-Nickel Electrodeposits.'

Trans. Inst. Metal Finishing, 1960, vol. 37, Autumn, pp. 108–9.

The commercially important tin-nickel electrodeposits contain approximately 65 wt. per cent. of tin, corresponding to approximately equi-atomic proportions of tin and nickel. The tin-nickel phase diagram indicates that an alloy of this composition, if in equilibrium, should consist of approximately equal proportions of the two intermetallic compounds Ni_3Sn_2 and Ni_3Sn_4 (at temperatures below 790°C.). Rooksby, who studied (by X-ray diffraction) the crystal structure of tin-nickel electrodeposits prepared in a manner described by Parkinson, found that in fact an equilibrium structure is not obtained. The deposits were single-phase and had a metastable nickel-arsenide-type structure similar to that of Ni_3Sn_2. This structure was stable up to 300°C., but decomposition into $Ni_3Sn_2+Ni_3Sn_4$ took place at higher temperatures. Since the plating solution now recommended for tin-nickel electrodeposition is rather different from that employed by Parkinson, it was decided to determine, by metallographic and X-ray examination, the structure and stability of the deposit obtained with this new solution. The results of the investigation are reported by the authors.

Tin-nickel alloy coatings containing 63–67 per cent. tin were deposited, onto brass, copper or steel substrates, from the solution recommended by the Tin Research Institute ($SnCl_2.2H_2O$ 50, $NiCl_2.6H_2O$ 250, $NH_4F.HF$ 40, ammonium-hydroxide solution 35, ml./L.).

The deposits were studied both in the as-plated condition and after heat-treatment in air for one hour at temperatures up to 700°C. In the as-plated condition they were found to be single-phase, exhibiting the nickel-arsenide type of structure. No change in the structure of the coating was determined after exposure for one hour at temperatures up to 500°C., but at 700°C. and above decomposition into the equilibrium two-phase condition occurred.

Electroforming in Pattern Construction and Repair

P. RITZENTHALER: 'Electroforming for Pattern Construction and Repair.'

Modern Castings, 1960, vol. 38, Sept., pp. 89–90.

In this article the author is principally concerned with the advantages to be derived from the application of electroforming to the production of foundry patterns. (Electroforming involves electrodeposition, onto a removable substrate of desired configuration, of a nickel deposit sufficiently thick to exhibit adequate mechanical properties independent of a basis metal, and, hence, suitable for use as, for example, a pattern.) The use of the process in this connexion is described in relation to the production of sand patterns, shell-moulding patterns and moulds for making wax patterns for precision casting.

The article also includes short sections on the use of nickel plating in (1) the salvage of worn or undersized patterns, and (2) the deposition of an abrasion-resistant coating on aluminium patterns.

NON-FERROUS ALLOYS

Standard Designations of Alloys and Steels Used in Aeronautical Applications

See abstract on p. 299.

Influence of Silicon and Aluminium on the Stability of Sigma Phases

K. P. GUPTA, N. S. RAJAN and P. A. BECK: 'Effect of Si and Al on the Stability of Certain Sigma Phases.'

Trans. Metallurgical Soc., A.I.M.E., 1960, vol. 218, Aug., pp. 617–24.

In the work reported the authors studied the effect of silicon and aluminium on the stability of various σ phases formed by first long period transition elements. The following systems were selected for investigation: V-Fe-Si, V-Co-Si, V-Ni-Si, Cr-Mn-Si, Cr-Co-Si, Cr-Ni-Si, V-Fe-Al, and Cr-Co-Al. In each of the systems (except the Cr-Mn-Si, which was investigated at 1000°C.) the boundaries of the σ phase were determined at 1175°C.

Isothermal sections of the relevant ternary phase diagrams show the boundaries established for σ in the various systems. Silicon was found to exert a stabilizing effect on the σ phases, while aluminium tended to de-stabilize them. Silicon atoms in solid solution occupy sites *D* in the σ structure. The c_o/a_o ratio increases with increase in silicon, manganese or iron content. The volume of the unit cell decreases with increase in silicon content.

Influence of Nickel on the Susceptibility of Beta Brasses to Intercrystalline Cracking

A. R. BAILEY: 'The Effect of Composition on the Intercrystalline Cracking of Sand-Cast, Complex Beta-Brasses under Constant Tensile Load.'

Jnl. Inst. Metals, 1960, vol. 89, Nov., pp. 110–11.

In common with other β-brasses, cast complex alloys of the 48-ton type (conforming to *B.S.* 1400-*H.T.B.*-3-*C*) are susceptible to intercrystalline cracking when subjected to sustained tensile stress. Cracking takes place in the ordinary atmosphere (provided that moisture is present) and especially in sea-water or 3 per cent. NaCl solution.

The purpose of the investigation described in the paper was to determine the influence, on the proneness of the material to cracking, of (1) the alloying elements aluminium, iron and manganese, and (2) nickel and cobalt additions. Tests on the alloys were conducted both in air and in 3 per cent. NaCl solution.

The conclusions drawn by the author from the results of the investigation can be summarized as follows:

The 48-ton β material was more susceptible to intercrystalline cracking when the alloy contained

the γ phase, but less so when a small amount of α phase was present (although in the latter case the strength was reduced).

Investigation of the influence of alloying elements demonstrated that aluminium produced the greatest strengthening effect, but increased the tendency to cracking. The maximum amount of aluminium which could be added as a ternary component without the occurrence of γ phase in the structure was approximately 4 per cent. However, when either iron or manganese was present, 5 per cent. or more of aluminium could be added without γ formation. The introduction of manganese did not increase strength as much as a single addition of 4 per cent. aluminium, and there was no improvement in cracking resistance. The presence of iron, in conjunction with 5 per cent. aluminium, enhanced both strength and cracking resistance. The iron, it is suggested, is probably most effective, especially at contents less than 2 per cent., when manganese is also present.

The addition of 2 per cent. nickel to the 48-ton alloy inhibited intercrystalline cracking, but nickel was effective only in the presence of iron (the content of which should preferably be greater than 2 per cent.). Cobalt additions, while also increasing resistance to cracking, tended to produce dezincification, with consequent weakening.

See, in connexion with this paper, *British Patent* 833,288 abstracted, under the head **Nickel-containing β-Brasses with Increased Resistance to Stress Corrosion,** in *Nickel Bulletin*, 1960, vol. 33, No. 7, p. 185.

Influence of Temperature on the Properties of Cupro-Nickels and Nickel Silvers

H. R. PRITCHARD: 'Survey of Literature on the Effect of Testing Temperature on the Properties of Wrought Copper-base Alloys.'

U.S. Department of Commerce, Office of Technical Services, Report R-1435, Feb. 1958; 90 pp.

The report collates data obtained from a review of the literature on the influence of temperature on the properties of wrought copper-base alloys tested at temperatures in the range −300° to +1500°F. (−185° to +815°C.).

The data are grouped according to the property to which they relate (tensile properties, modulus of elasticity, hardness, fatigue strength, electrical resistivity and thermal conductivity). Within these groups the alloys are listed according to the major alloying element (un-leaded brasses; leaded brasses; aluminium and tin brasses; aluminium bronzes; phosphor bronzes; silicon bronzes; 30 and 10 per cent. cupronickels; 65-18, 65-10 and 55-18 nickel silvers), and, where data of different origin are available on the same property of a specific alloy, an attempt has been made to classify the results according to the form or condition of the material.

Compared with room-temperature values, exposure to low-temperatures has, it is concluded, the effect of increasing tensile and yield strengths, elongation, modulus of elasticity, hardness, and fatigue strength. Reduction-in-area is usually not significantly affected, and electrical resistivity decreases with fall in temperature.

Exposure to elevated temperatures decreases tensile and yield strengths, modulus of elasticity and hardness, and increases thermal conductivity and electrical resistivity. Interpretation of the data available on the influence of elevated temperatures on elongation was difficult, due to the interrelated effects of other factors such as chemical composition and history of the material. No data were available on fatigue properties at elevated temperatures.

Casting Characteristics of High-Manganese Nickel-Aluminium Bronze

G. BRADSHAW, M. M. KENNEDY and S. H. DORN: 'High-Manganese Nickel-Aluminium Bronze: Casting Characteristics.'

Modern Castings, 1960, vol. 38, Sept., pp. 67–74.

The test programme reported was conducted within the scope of a test programme initiated (under the aegis of the U.S. Bureau of Ships) to determine the suitability, for marine propellers, of a high-manganese nickel-aluminium bronze of the following composition: copper 75·04, manganese 12·1, aluminium 7·7, iron 2·85, nickel 2·25, silicon 0·06, per cent. The programme was intended to establish the foundry characteristics of the alloy, a prerequisite to any subsequent production of a propeller suitable for evaluation under service conditions.

The following factors were studied: fluidity and mechanical properties (in each case as a function of pouring temperature); drossing and risering characteristics and the sensitivity of the mechanical properties to section size (these factors were studied in relation to two castings, one with a straight riser, the other with a tapered riser, intended to simulate propeller castings); grain-size. Data obtained on nickel-aluminium bronze and manganese bronze served as a basis of comparison in the evaluation of the alloy.

The yield point of the alloy, determined using keel-block specimens, was about 7,500 p.s.i. higher than that of nickel-aluminium bronze. Its ultimate tensile strength was, however, only slightly superior, and ductility was about equal.

The yield strength of specimens taken from the simulated propeller (a 2-in. blade section attached to a hub 12 in. in diameter and 24 in. high) was found to be 5,500 p.s.i. greater than that of the nickel-aluminium bronze in the 12-in. section, and 5,700 p.s.i. greater in the 2-in. section; the ultimate tensile strength of the high-manganese bronze was slightly superior, but elongation values were similar. The alloy will, it is considered, satisfy minimum mechanical-property requirements when melted to the minimum chemistry and poured into dry-sand, baked-sand and cement moulds.

The alloy was satisfactorily fluid at pouring temperatures of 1900°F. (1035°C.) and 1975°F. (1080°C.): these temperatures compare with 2050°F. and 2150°F.

(1120° and 1175°C.) for nickel-aluminium bronze, and 1800° and 1850°F. (980° and 1010°C.) for manganese bronze. In the gating and risering tests the alloy exhibited many of the characteristics of nickel-aluminium bronze, and the precautions taken with the latter material are considered applicable also to the former. Drossing characteristics were similar to those of nickel-aluminium bronze.

Mechanical properties decreased with increase in section size, but only to a degree (comparable to that associated with nickel-aluminium bronze) which is not considered excessive. Grain-size increased only slightly with increase in section from 2 in. to 12 in.

Although the manufacturers of the high- manganese bronze recommend that the silicon content of the alloy be held to 0·05 per cent. max., the specimens studied in the present investigation were melted in silicon-carbide crucibles with no apparent effects on mechanical properties or silicon pick-up.

Formulae for Rapid Calculation of Furnace Charges

L. M. ELIJAH: 'How to Make Castings with Correct Composition.'

Modern Castings, 1960, vol. 38, Sept., pp. 50–2, 54, 56.

The author presents, and illustrates the application of, formulae which permit accurate and rapid calculation of the furnace charges necessary to modify the composition of a given melt. Formulae enabling calculation of the overall furnace adjustments entailed in maintaining the composition of a polynary alloy within narrow specification limits (exemplified by the author in relation to the production of a nickel-aluminium bronze) are stated to be applicable to all types of alloy.

The article includes a nomograph for

$$X = \frac{C(A-B)}{100-A}$$

where C is the original weight of melt, B is the original percentage of the element X in the alloy, A is the final percentage of the element X desired in the alloy, and X is the weight of the element X to be added.

Electroforming in Pattern Construction and Repair

See abstract on p. 304.

'Inco-Weld A' Welding Electrode and Filler Wire

See abstract on p. 321.

NICKEL-IRON ALLOYS

Martensite Transformation in Iron-Nickel Alloys

W. S. OWEN and A. GILBERT: 'The Kinetics of the Martensite Transformation in Iron Alloys.'

Jnl. Iron and Steel Inst., 1960, vol. 196, Oct., pp. 142–9.

A detailed account of the kinetics of martensite reactions was published two years ago by KAUFMAN and COHEN (see '*Progress in Metal Physics, VII*', 165, 1958; *Pergamon Press*, London). In the present review the authors have, as far as possible, avoided duplication of material considered in that account, and have confined their discussion to iron-base alloys. Nevertheless they consider that 'sufficient new information has been published since the Kaufman and Cohen review to warrant further general discussion, and it seems particularly important to direct attention to those areas in which at present there is a surfeit of conflicting ideas'.

Martensite transformations are classified according to the crystal structure of the product, and the driving force required for the transformation in iron-nickel alloys is compared with that necessary in iron-chromium and iron-carbon alloys. The kinetics of martensite formation is briefly considered in terms of the nucleation of new martensite plates and the variation with temperature of the fraction of austenite transformed. The paper ends with a critical review of some recent ideas on stabilization effects.

Carburization and De-Carburization of Iron-Nickel Alloys

P. GENDREL and L. JACQUÉ: 'On the Properties of Nickel Austenites.'

Comptes Rendus, 1960, vol. 250, June 20, pp. 4151–3.

The investigation reported was initiated to throw light on the influence of nickel on the kinetics of carburization and de-carburization of iron-nickel alloys.

Four materials were selected for study: 'Armco iron'; two iron-nickel alloys containing 2 and 5 per cent. nickel, respectively; and a high-purity grade of iron specially prepared for the test programme. The specimens were subjected, at temperatures in the range 910°–960°C., to (1) a flow of purified hydrogen, or (2) a hydrogen/methane mixture, and the de-carburization and carburization reactions were studied, using thermogravimetric techniques, as a function of the nickel content of the specimens studied. The kinetic data obtained from the experiments are summarized in the present note.

Properties of Iron-Nickel and Iron-Copper-Nickel Sintered Materials

G. FINDEISEN: 'Some Sintered Steels Alloyed with Copper and Nickel: Their Properties and Production.'

Metall, 1960, vol. 14, Oct., pp. 995–8.

The investigation reported was undertaken to investigate (1) the properties of iron-nickel sintered alloys, with particular respect to the influence of variables of practical interest, and (2) the feasibility of combining the advantages offered by copper additions (e.g., less intensive sintering, lower cost, and greater control over dimensional changes during sintering) with those associated with the iron-nickel alloys (e.g., high strength).

Tensile specimens of iron-nickel and iron-copper-nickel alloys were produced by compacting and

sintering powder mixtures of the constituent elements, and experiments were carried out to determine tensile strength, elongation, density, Brinell hardness, and dimensional changes resulting from sintering. The results of these experiments were supplemented by those of a metallographic study.

The data included by the author indicate that addition of nickel considerably increases the strength and ductility of sintered iron, an effect which is greatly enhanced by double compacting and sintering.

Ternary iron-base alloys containing 2·5–7·5 wt. per cent. nickel and 2 per cent. copper were found to exhibit attractive properties: e.g., relatively high strength (45 kg./mm.^{2}) and elongation (5 per cent.), combined with small dimensional changes during sintering, a sintering time of only 1 hour, and resistance to the furnace atmosphere. The data presented indicate that strength was at a maximum at a content of 5 per cent. nickel and 5 per cent. copper: this maximum was, however, associated with an elongation of only 3·5 per cent. and a linear dimensional change of +1·6 per cent.

Internal Ferromagnetic Resonance and Magnetostatic Modes in Nickel-Iron Alloys

J. C. ANDERSON: 'Internal Ferromagnetic Resonance and Magnetostatic Modes in Nickel-Iron Alloys.'

Proc. Physical Soc., 1960, vol. 76, Aug. 1, pp. 273–81.

In an earlier paper, reporting internal-resonance measurements on small cobalt particles precipitated in a copper matrix, the author demonstrated that the value of the internal field which represents the magneto-crystalline anisotropy (determined from the variation with frequency of the complex permeability) showed good agreement with that calculated from anisotropy constants measured by static methods. In the experiments now described, carried out using colloidal suspensions of nickel-iron alloys in paraffin wax, the total internal magneto-crystalline anisotropy field was measured, by internal ferromagnetic resonance, as a function of alloy composition.

The variation of the internal field with composition was found to be in agreement with previous qualitative observations obtained by a different technique. The results reveal that the total anisotropy passes through a minimum in the region of 65 per cent. nickel: values for the anisotropy constants K_1 and K_2, calculated from the results, are compared with published values.

Multiple peaks in the permeability/frequency curves are interpreted as magnetic resonance modes of different order.

Magnetic Materials Used in the Communications and Electronic Industries

C. GORDON SMITH: 'Magnetic Materials: A Survey of those Used in the Communications and Electronics Industry.'

Electrical Rev., 1960, vol. 167, Aug. 12, pp. 253–9.

Magnetic materials have played a vital rôle in the development of electrical technology. Their applications fall into two distinct categories: those involved in the distribution of energy, and those associated with the communications and electronic industries. In the power engineering field the main materials used (iron or steel, sometimes with minor additions of silicon and other elements) satisfy the basic requirements of permeability and saturation at an essentially low cost. The materials used in communications engineering must meet stringent specifications, and are more often complex alloys, many of which contain nickel (and sometimes cobalt) and, frequently, minor additions selected from a very wide range of other elements.

The present review is concerned with magnetic materials and their applications in communications engineering. It opens with a survey of the development, salient characteristics and advantages of the more important types of material in current use: nickel-iron alloys, magnetostrictive materials, permanent-magnet materials, ferrites, and constant-permeability materials. Data are tabulated on the magnetic properties of commercially available materials representative of those falling within the classes discussed.

In the second half of the review, consideration is given to the applications which the various materials find in line communications, radio and television, instrumentation, automation and computation.

CAST IRON

Influence of Double Tempering on the Life of 'Ni-Hard' Grinding Balls

R. H. T. DIXON: ''Ni-Hard' Grinding Balls Far Outlive Steel.'

Engineering, 1960, vol. 190, No. 4, pp. 598–9.

In addition to abrasion, grinding balls are subjected in service to repeated light impact. In the case of balls made from the nickel-chromium abrasion-resistant white cast iron 'Ni-Hard', it has been found advantageous to apply heat-treatments designed to temper the as-cast martensite and, at the same time, to transform retained austenite to bainite and/or tempered martensite. Work at the laboratory of The Mond Nickel Company, Ltd., has demonstrated that correctly tempered sound 'Ni-Hard' balls exhibit impact-fatigue lives far longer than those which can be expected from similar balls in the as-cast condition. Such improvement has been shown, for example, in 2½-in.-diameter (5·6-cm.-diameter) sand-cast 'Ni-Hard' balls tempered for 4 hours at 450°C., followed by 4 hours at 275°C.

To assess the practical validity of these laboratory findings, double-tempered balls were tested in a ball mill, under normal commercial conditions, at the Mond Nickel Company's refinery in Clydach, South Wales. A batch of 200 2½-in.-diameter sand-cast balls of the following composition were given

the double-temper heat-treatment referred to above, and were then used to replace a similar number of forged medium-carbon-steel balls in the second compartment of a Schmidt ball mill of 6-ft. (1·8-m.) internal diameter: carbon 3·2, manganese 0·5, silicon 0·3, sulphur 0·01, phosphorus 0·03, nickel 3·8, chromium 1·8, per cent.

Service Tests on 'Ni-Hard' Grinding Balls
(See abstract on page 307)

Charge material	Nickel oxide sinter plus fine metallics: size $\frac{3}{8}$ in. to fines.
Balls currently used	Steel.
Temperature of charge in mill	50°-70°C.
Balls in first compartment	2000 lb.: 70 mm. 5000 lb.: 50-60 mm. 2000 lb.: 50 mm. } Steel
Balls in second (test) compartment	2000 lb.: 60 mm. 4000 lb.: 50-60 mm. 2500 lb.: 40-50 mm. } Steel 310 lb.: 56 mm.: 'Ni-Hard'
Speed of mill	20-21 r.p.m.
Balls added each week: first compartment	700 lb.: 70 mm. } Steel.
second (test) compartment	600 lb.: 60 mm. } Steel.
Complete ball removal, and re-grading of steel balls	every 3 months (approx.).
Rate of wear on 9000 lb. steel balls	1·8 lb. per short ton of sinter milled.
Calculated rate of wear on 9000 lb. 'Ni-Hard' balls	0·084-0·127 lb. per short ton of sinter milled.
Size of 'Ni-Hard' liners, with cement-asbestos backings	2 ft. 6 in. square by 2-3 in. thick.
Mill division grids	Slotted Hadfields manganese steel (these slots tend to close up during service).
Mill output	Approx. 100 tons per day (5·7-6·0 tons per hour).
Internal diameter of mill	6 ft.
Daily operating cycle	18 hours milling, 5-6 hours stationary (usually shut-down in the early hours of the morning).

Details of mill operation and the data obtained are given in a table which is reproduced above. The mill operates under dry conditions, with a normal air-current discharge. The 'Ni-Hard' balls were added during the normal weekly ball check, and during the following week the mill was opened daily to examine the balls for wear and breakage. Re-grading was carried out at approximately three-monthly intervals. On these occasions all the 'Ni-Hard' balls were removed from the mill, inspected, and weighed prior to being replaced in service The rate of wear under these conditions is illustrated in the article. When the wear rate is calculated as if all the 9,000 lb. charge were in 'Ni-Hard', the total loss would be 0·084 lb. per short ton of sinter ground with 56-mm. balls, or 0·127 lb. per short ton with 50-mm. balls (the latter calculated from losses on worn balls). These figures compare favourably with those for the forged medium-carbon-steel balls normally used (1·8 lb. per short ton with a mixed charge of 50-70 mm. diameters). The wear factor in favour of alloy cast iron is therefore at least 14 : 1, and would approach 20 : 1 if the initial size distribution were retained. No evidence of breakage or spalling was found in any of the 'Ni-Hard' balls examined.

It is considered that, in the Clydach plant, operating costs and contamination of the ground product would be decreased by a complete changeover to 'Ni-Hard' grinding media (the liner plates used in this mill are already in 'Ni-Hard'). The initial cost per ton of forged steel balls is about £60, compared with £120 for the same weight of 'Ni-Hard' balls, but, taking into account the wear factor, the ball-cost per ton of ore ground would be only about 1·65d. for 'Ni-Hard' as compared with 11·5d. for steel.

Electroforming in Pattern Construction and Repair

See abstract on p. 304.

CONSTRUCTIONAL STEELS

Standard Designations of Alloys and Steels Used in Aeronautical Applications

See abstract on p. 299.

Properties of Nickel-Chromium-Molybdenum-Vanadium High-Purity High-Strength Steels

J. M. CAPUS and G. MAYER: 'The Mechanical Properties of Some Tempered Alloy Martensites.'
Jnl. Iron and Steel Inst., 1960, vol. 196, Oct., pp. 149-58.

In a paper published in *Revue de Métallurgie*, 1959, vol. 56, Aug./Sept., pp. 181-9, CAPUS demonstrated that '350°C. embrittlement' was eliminated in vacuum-melted and -cast nickel-chromium-molybdenum steels produced from pure base materials. Tests on similarly prepared steels to which various impurity elements had been added indicated that such embrittlement could be induced by the presence of small amounts of phosphorus, arsenic, antimony, tin and nitrogen, or by larger quantities of manganese (up to 2 per cent.) or silicon (up to 1·5 per cent.). The nitrogen content (0·02 per cent.) was higher than would be normally encountered in commercial steels, but the results obtained suggested that vacuum melting could have beneficial effects on the impact properties of tempered martensite, provided that the contents of other impurities were low. In the preamble of the present paper the authors refer to the influence of silicon as being of particular interest in view of the practical use which has been made of this element in several types of ultra-high-strength

steel developed in the U.S.A. for aeronautical applications: the data available indicate that the tempering range in which embrittlement is encountered increases towards 450°C. with rise in silicon content.

The absence of '350°C. embrittlement' in high-purity nickel-chromium-molybdenum steels suggested the possibility of developing improved ultra-high-strength steels on this basis : it was expected that higher impact values might be obtained at strength levels attainable only by tempering at temperatures, which, for commercial-purity steels, would be in close proximity to, if not within, the embrittling temperature range. Work was therefore undertaken to provide further information on the mechanical properties of high-purity martensites alloyed with nickel, chromium, molybdenum, vanadium and silicon. This work forms the subject of the present paper.

Two series of the following grades of steel were prepared for study: 1½ per cent. nickel-chromium-molybdenum, 1·8 per cent. nickel-chromium-molybdenum - vanadium, 4¼ per cent. nickel - chromium - molybdenum - vanadium, and 4¼ per cent. nickel-chromium-molybdenum-vanadium containing approximately 1·5 per cent. silicon. One of the series was vacuum-melted and -cast from high-purity raw materials; the other series comprised steels of commercial purity induction-melted in air. All the steels, in the form of round bar, were oil-hardened, tempered for 1 hour in the range 200-500°C. and water-quenched. Tensile, impact, notch-tensile, and plain-bar and notch-fatigue tests were carried out at room temperature, and impact properties were determined also at −78°C.

The data presented by the authors demonstrate that the removal of impurities normally present in high - strength nickel - chromium - molybdenum - vanadium steels results in improved impact properties, tensile ductility and notch-tensile strength. Raising the carbon content was found to have a markedly deleterious influence on impact properties (an effect which was more clearly revealed by the tests on the high-purity materials than by those on steels containing impurities at normal commercial levels).

The silicon additions modified the tempering characteristics of martensite, giving some practical advantage in steels of commercial impurity. In high-purity steels, however, the amount of silicon added (1·5 per cent.) had detrimental effects on impact properties and tensile ductility, and such steels offered no advantages *vis-à-vis* commercial-purity types.

Plain-bar fatigue tests revealed no endurance limits, and the results indicate that finite-life fatigue strengths are not affected by the purity of steels heat-treated to strengths of about 120 tons/in.² (189 kg./mm.²: 268,800 p.s.i.): in notched-bar fatigue tests, steels of this strength level did, however, show an endurance limit. The preliminary data already established indicate that, as regards both finite-life fatigue stress and endurance limit, high-purity steels are slightly superior to those of commercial purity.

Relationship between the Tensile Strength and Hardness of Nickel-Chromium-Molybdenum Steel at Low Temperatures

J. NUNES and F. R. LARSON: 'Low-Temperature Tensile-Hardness Correlations of S.A.E. 4340 Steel.' *U.S. Department of Commerce, Office of Technical Services, Tech. Report WAL TR* 320 4/1, Feb. 1960; 18 pp.

The Vickers hardness (D.P.H.) and tensile strength (U.T.S.) of specimens from one heat of S.A.E. 4340 nickel-chromium-molybdenum low-alloy steel were studied, as a function of test temperatures ranging from room temperature to −196°C., to determine (1) if a relationship could be established between hardness and the test temperature; (2) if the existing hardness/tensile correlation is valid at the lower testing temperatures.

Specimens of the steel were heat-treated to produce martensitic, bainitic or pearlitic structures of various strengths, and then subjected to hardness and tensile tests.

On the basis of the data presented, the following conclusions* are drawn:

'1. Vickers hardness (D.P.H.) is a linear function of reciprocal absolute temperature for S.A.E. 4340 steel within a temperature range of room temperature to −196°C., whose formula can be derived, taking the form:

$$\text{D.P.H.} = \frac{M}{T} + C$$

'2. A formula expressing Vickers hardness at any temperature between room temperature and −196°C., independent of the strength levels and structures studied, can be derived taking the form:

$$\text{D.P.H.}_T = M(1/T - 1/RT) + \text{D.P.H.}_{RT}$$

'3. Tensile strength (U.T.S.) is a linear function of reciprocal absolute temperature, whose formula can also be derived, similar to that of Vickers hardness, taking the form:

$$\text{U.T.S.} = N/T + C_1$$

'4. A formula expressing tensile strength at any temperature between room temperature and −196°C., independent of the strength levels and structures studied, can be derived, taking the form:

$$\text{U.T.S.}_T = N\,(1/T - 1/RT) + \text{U.T.S.}_{RT}$$

'5. Vickers hardness is a linear function of the testing-temperature range studied (room temperature to −196°C.), independent of the heat-treatment and structures used in this experiment (martensite, bainite and pearlite).

'6. The above correlation of Vickers hardness with tensile strength is in agreement with the S.A.E. correlation and also with other low-temperature data points for other steels, indicating that this correlation may be valid for most steels, independent of testing temperature.

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*M = slope of hardness/temperature curve.
N = slope of tensile/temperature curve.
T = absolute test temperature in °K.
C or C_1 = material constant or intercept at 1/T = O.
RT = room temperature.

'7. A formula for obtaining the approximate tensile strength of S.A.E. 4340 at the lower testing temperatures may be derived in such a manner that only the room-temperature hardness of the steel need be known:

$$U.T.S._T = 465[M(1/T - 1/RT) + D.P.H._{RT}].'$$

Influence of Niobium on the Hardenability of Low-Alloy Steels

M. P. BRAUN, B. B. VINOKUR and V. A. KAMALOV: 'Hardenability of Columbium-Alloyed Steel.'

Izvest. V.U.Z., Chern. Met., 1960, Mar., pp. 140–5. *Henry Brutcher, Translation No.* 4841.

Additions of up to 0·33 per cent. niobium were made to chromium-nickel, chromium-manganese-nickel and chromium-manganese-silicon low-alloy structural steels, and the following variables were studied as a function of such additions: (1) stability of undercooled austenite during isothermal holding and continuous cooling; (2) strength, ductility and toughness; (3) temper brittleness and brittle failure at low temperatures; (4) inter-atomic bonding forces of the α-iron lattice; (5) hardenability. In a supplementary study, end-quench data obtained for a chromium-molybdenum-vanadium steel (carbon 1, chromium 1·9, molybdenum 0·3, vanadium 0·2, per cent.) widely used for cold-rolling rolls were compared with those obtained in end-quench tests on specimens in which the vanadium content of the steel had been replaced by 0·11, 0·2 or 0·3 per cent. niobium.

From the data presented the authors conclude that the stability of undercooled austenite during isothermal holding and continuous cooling increases with increase in the niobium content. The niobium-containing specimens exhibited higher tensile properties and ductility than the same grades without niobium. The mechanical properties of the former steels in the quenched-and-tempered condition approached those of molybdenum steels and tungsten-containing steels. Depending on the composition of the steel, the presence of niobium can, it is concluded, improve toughness and reduce susceptibility to temper embrittlement and brittle fracture at low temperatures.

Addition of niobium to a steel containing weak carbide-formers has a beneficial effect on mechanical properties and hardenability (hardenability is increased to the level associated with tungsten-containing steel).

The end-quench tests on the chromium-molybdenum steel demonstrated that hardenability is considerably higher in the presence of niobium, and that the depth of the hardened case increases with increase in niobium content.

Influence of Carbon Content on the Notch Properties of Nickel-Chromium-Molybdenum Steel

E. P. KLIER: 'The Effect of Carbon Content on the Notch Properties of 43XX Vanadium-Modified and 5 per cent. Chromium Sheet Steels.'

Amer. Soc. Testing Materials, 1960, *Preprint* 76c; 12 pp.

Carbon content is one of the factors thought to influence the notch-sensitivity of high-strength steels, and recently considerable increases in the notch strength of '300M' sheet steel have been reported to have been achieved with suitable reduction in carbon content. Strength level has also been considered a significant factor. In the work now described, the notch properties of vanadium-modified low-alloy nickel-chromium-molybdenum steels of A.I.S.I. 43XX type were studied as a function of carbon content and strength level (the steels were hardened and tempered at temperatures in the range 400°–800°F. (205°–425°C.)). Specimens of 'Vascojet X-2' and 'Vascojet 1000', heat-treated to hardnesses in the range Rc 40–50, were likewise tested.

The compositions of the materials studied are given in the table below. Edge-notched tension specimens

Composition of High-Strength Steels

(*See abstract above*)

Element %	4321-Vanadium	4330-Vanadium	4341-Vanadium	4350-Vanadium	4360-Vanadium	'Vasco X-2'	'Vascojet 1000'
Carbon ..	0·21	0·30	0·41	0·50	0·60	0·24	0·39
Silicon ..	0·22	0·31	0·34	0·34	0·33	0·89	0·83
Manganese	0·60	0·75	0·74	0·65	0·68	0·32	0·33
Sulphur ..	0·023	0·027	0·030	0·030	0·029	0·017	0·011
Phosphorus	0·015	0·018	0·013	0·018	0·020	0·016	0·017
Chromium	0·80	0·81	0·82	0·80	0·81	4·91	4·94
Vanadium..	0·20	0·20	0·18	0·20	0·19	0·54	0·48
Molybdenum	0·35	0·37	0·36	0·35	0·37	1·30	1·30
Nickel ..	1·81	1·79	1·85	1·83	1·87	—	—

were tested at temperatures in the range +85° to −320°F. (+30° to −195°C.).

The results show that the oil-quenched 43XX vanadium-modified steels did not harden to the value ideally expected for the respective carbon contents. The data also indicate a discontinuous change in properties over the carbon-content range 0·3-0·4 per cent. At 85°F. (30°C.), the nickel-chromium-molybdenum steels studied failed by low-energy shear; as the test temperature was lowered, the high-carbon materials failed by flat brittle fracture. The three steels of lowest carbon content tended, with decrease in test temperature, to develop high-energy shear fractures and, at the minimum temperatures, also failed in the flat brittle manner.

The 5 per cent. chromium steels failed by high-energy shear and flat brittle fracture, and the ductile/brittle transition temperature was slightly higher in material of lower carbon content.

The notch-strength/test-temperature curves did not reveal a ductile/brittle transition for all the steels, but, where this ductile/brittle transition did exist, it lay significantly below ambient temperature.

The author concludes that reduction in carbon content improves the notch toughness of the 43XX vanadium-modified steels. Due to a corresponding reduction in the yield strength, however, optimum performance is associated with intermediate carbon contents in the range 0·3-0·35 per cent. It is suggested that properties are optimum at that strength level at which the notch strength is equal to the yield strength. On the basis of this criterion, the optimum yield strength for the 43XX steels studied is stated to be in the region of 175,000 p.s.i. (73·5 t.s.i.: 116 kg./mm.^{2}): for the 5 per cent. chromium steels the value is slightly higher.

Resistance of Nickel-containing Steels to Hydrogen Embrittlement

See abstract on p. 315.

Comparison of Embrittlement in Austenitic and Ferritic Steels

See abstract on p. 315.

Influence of Cold Work on the Fatigue Properties of Nickel Steel

N. E. FROST: 'The Effect of Cold Work on the Fatigue Properties of Two Steels.'

Metallurgia, 1960, vol. 62, Sept., pp. 85-90.

The notch fatigue strength of a material might be expected to be dependent on the machining processes used to form the notch, since different processes will subject the material at the notch root to varying degrees of work hardening and induce different values of residual stress. Though the results of studies of notched mild-steel specimens indicated that residual stresses may have little effect, the author has, in a previous paper, demonstrated that, for moderate amounts of cold work, the fatigue strength of the material increases approximately linearly with the amount of cold work. On the other hand, with, for example, notched specimens of high-strength alloy steels, the induced residual stresses may be influential, whereas little increase in the fatigue strength of the material may result from cold work. To determine the maximum possible increase in fatigue strength resulting solely from cold work, blanks of mild steel and 2½ per cent. nickel-chromium steel were subjected to varying amounts of cold work, and specimens cut from the worked blanks were then subjected to fatigue tests. The results of these tests are discussed in the present paper.

The data demonstrate that an appreciable increase in the fatigue limit can be achieved by cold working mild steel, there being an optimum value for the amount of prior strain at which the maximum fatigue limit occurs. There is some indication that the fatigue limit of the 2½ per cent. nickel-chromium alloy steel may be slightly increased by cold work.

All-Position Welding of 'HY-80' Steel

C. R. SIBLEY: 'All-Position Welding of 'HY-80' Steel with the Gas-Shielded Process.'

Welding Jnl., 1960, vol. 39, Oct., pp. 433s-7s.

'HY-80' low-alloy steel* was selected as a material of construction for use in American atomic submarines because (1) it exhibits moderate strength, combined with excellent toughness and ductility, at all the anticipated service temperatures, and (2) it can be readily welded, using available processes, to give welds which are sufficiently tough to withstand repeated ballistic loading without failure. In this application, plates of 'HY-80' steel (⅜-3 in. thick) are joined by groove-welded butt and tee joints, and the military specifications call for weld metal which, deposited without defects, exhibits tensile properties similar to those of the basis metal, and has a minimum Charpy V-notch impact strength of 20 ft.-lb. at −60°F. (−50°C.). The gas-shielded metal-arc welding process, which has been found capable of depositing weld metal satisfying these requirements, is currently restricted to the flat position of welding, since, with an open arc in argon, the weld metal is too fluid to control easily in other positions. The increasing use of 'HY-80' steel has focused attention on the need to develop a gas-shielded technique suitable for use in all welding positions. This paper reports an investigation which was carried out with the aim of developing a technique which, involving use of *MIL-B*88 welding wire†, would satisfy this need.

* Composition: carbon 0·22 max., manganese 0·1-0·4, silicon 0·12-0·3, phosphorus 0·04 max., sulphur 0·045 max., nickel 2·0-3·25, chromium 0·85-1·9, molybdenum 0·15-0·65, per cent.

† Composition: carbon 0·05, manganese 1·42, silicon 0·52, phosphorus 0·009, sulphur 0·015, nickel 1·43, chromium 0·08, vanadium 0·15, molybdenum 0·46, per cent.

In welding mild steel, use of a 100 per cent. carbon-dioxide shield and an appropriate power supply enables an arc to be established in which metal is not overheated by the arc and does not fall out of the vertical or overhead joint. This type of transfer in carbon-dioxide shielding, known as 'dip transfer', is capable of depositing high-quality weld metal, in all positions, on mild steel of various thicknesses. Pure carbon-dioxide shielding cannot be used to weld 'HY-80' steel with *MIL-B*88 welding wire, because the tensile and impact properties are reduced below those required in *MIL-E*-19822 (*Ships*). Addition of carbon dioxide to the argon shield, however, produces a desirable dip-transfer type of arc. In the initial stages of the present study, therefore, it was considered necessary to determine if the amount of carbon dioxide required to develop a good transfer for all-position welding would also produce weld metal of the strength and toughness necessary to weld 'HY-80' steel.

An 80/20 argon/carbon-dioxide mixture was found suitable as a shielding gas, and, subsequently, explosion-bulge tests were made on welded specimens produced, in the overhead and horizontal positions, using this shield and a 0·035-in. (0·875-mm.) welding wire. The failure of butt welds during these tests was attributed to lack of fusion at the locations of starts within the joint or between the weld deposit and the plate. Additional tensile, impact and side-bend tests on welded specimens produced employing 0·062-in. (1·55-mm.) *MIL-B*88 welding wire (use of this wire was intended to make the arc area larger, and, hence, to make the joint easier to weld) revealed no fusion defects in the weldment. A series of 1-in. (2·5-cm.) 'HY-80' bulge plates were therefore welded vertically, using the 0·062-in. wire and a four-pass technique. Even though previous tests had shown that good quality weld metal can be deposited in the vertical position with this new technique, failures occurred in the heat-affected zone of the plate specimens during ballistic testing, and approval of the process for use in all-position welding has consequently been withheld. Modification of the welding technique to lower the energy input will, it is anticipated, ensure production of welds which will satisfactorily withstand ballistic testing.

The 'dip-transfer' welding technique described is stated to be suitable for quality welding of other types of steel in all positions and thicknesses.

Influence of Electroplating on the Fatigue Strength of the Substrate Material

See abstract on p. 302.

'Inco-Weld A' Welding Electrode and Filler Wire

See abstract on p. 321.

HEAT- AND CORROSION-RESISTING MATERIALS

Powder-Metallurgical Production of High-Temperature Alloys: Bibliography

V. D. BARTH: 'Selected References on Making High-Temperature Alloys by Powder Metallurgy.'

Defense Metals Information Center, Battelle Memorial Inst., Memorandum 47, Mar. 18, 1960; 4 pp.

Commenting on the 33 references selected for inclusion in the *bibliography*, the compiler alludes to the lack of any comprehensive literature covering the application of powder metallurgy to the production of refractory materials *per se*, and emphasizes that the references are confined to literature which might serve as useful guides in planning the production of heat-resisting alloys.

The items are classified, according to their subject matter and scope, as follows: general references on powder metallurgy; general references on diffusion of metals; transition-metal interstitial-atom alloys; high-melting-metal alloys.

Production and Properties of Dispersion-Hardened Alloys

K. M. ZWILSKY and N. J. GRANT: 'Recent Advances in Dispersion-Strengthened Metal/Metal-Oxide Structures.'

Amer. Soc. Mechanical Engineers, 1960, *Paper* 60-*MET*-12; 12 pp.

Dispersion hardening, which has been the subject of considerable attention in recent years, is achieved by the dispersion, throughout a suitably ductile metallic matrix, of an inert hard strong second phase, of submicron size, which may be metallic, intermetallic or non-metallic. Storage of energy, obtained by a deformation process entailing a high strain rate (e.g., extrusion), then produces a strong structure unusually resistant to recovery and recrystallization processes (even at temperatures approaching the melting or transformation temperature of the metal or alloy matrix). In contrast to age-hardened alloys, the second phase is not subject to coalescence and re-solution, and, the size and distribution of the particles thus remaining unchanged in the matrix, the structure is stable at temperatures up to the melting point of the base metal.

Dispersion of the second phase is usually achieved either by mechanical mixing (i.e., the two constituents of the alloys are mechanically mixed in powder form and then compacted and extruded) or by internal oxidation (i.e., a dilute solid solution, consisting of a noble solvent metal and less-noble solute constituent, is subjected to a partial pressure of oxygen sufficient to oxidize the solute element and form a fine dispersion of oxide particles, leaving the solvent metal unaffected). In this paper, which is based on a *bibliography* of 35 items, the author reviews information and data available in the literature on

dispersion hardening, and, in particular, those findings which throw light on the advantages, limitations and relative efficacy of the mechanical-mixing and internal-oxidation techniques.

Mechanical mixing is discussed in relation to work reported on the copper/metal-oxide, cobalt/metal-oxide and molybdenum/metal-oxide systems and on nickel- and titanium-base alloys. The results obtainable by internal oxidation are illustrated by data available on copper-aluminium and copper-silicon alloys.

In the concluding section of the review, alternative methods of achieving fine-particle dispersions (i.e., by selective reduction of oxides or by decomposition of inorganic chemicals) are briefly outlined, attention is drawn to theories advanced in explanation of dispersion hardening, and finally consideration is given to potential fields of application (mainly those in which the improvements achieved in creep-resistance may be used to maximum advantage).

Standard Designations of Alloys and Steels Used in Aeronautical Applications

See abstract on p. 299.

Properties and Applications of Nickel-base Heat-Resisting Alloys

HENRY WIGGIN AND COMPANY, LTD.: 'Wiggin Heat-Resisting Alloys.'

Publn. 2139, 1960; 116 pp.

The last twenty years has seen a trend both towards the use of higher operating temperatures in almost every field of industry, and towards the use of materials which, exhibiting higher strength/weight ratios, permit the engineer to reduce proportionately the weight and section of equipment operating at such temperatures. Inevitably, however, the usefulness of any material is limited, by the service conditions, to a certain temperature range. This publication draws attention to some of the factors involved in the selection of the most suitable heat-resisting alloy for a specific application, summarizes the properties of the nickel-base heat-resisting alloys produced by HENRY WIGGIN AND COMPANY, LTD., and reviews, by way of illustration, some of the applications for which these alloys have been found suitable in various fields of industry. The information contained in the publication is therefore presented in three main sections.

In the first, the selection of the most suitable heat-resisting alloy for a given application is discussed in the light of economic factors and the corrosion-resistance and mechanical and physical properties of the material. Points raised under the heading of mechanical properties include: strength at high temperatures; creep and stress-rupture properties; resistance to thermal fatigue. The influence of corrosion-resistance is considered in sub-sections concerned with: oxidation behaviour; effect of heating and cooling; evaluation of resistance to oxidation; effect of steam; carburization; reaction to atmospheres containing nitrogen, halogens or sulphur; 'green rot'; attack by fuel ash; attack by molten metals; limiting service conditions.

The second section of the publication presents data illustrating the properties obtainable in the following heat-resisting materials: 'AT Nickel', 'Inconel', 'Incoloy', 'Incoloy DS', 'Nimonic 75', 'Nimonic 80A', 'Nimonic 90', 'Nimonic 105'. Data are tabulated on room- and elevated-temperature tensile properties, physical properties, stress-rupture properties, and creep properties.

In the final section, attention is drawn to applications typical of those which the high-nickel alloys find in: furnaces and heat-treatment equipment; gas carburizing; pack carburizing; salt-bath carburizing; salt-bath heat-treatment; nitriding; carbo-nitriding; brazing; sintering; sintering moulds; metal reduction; enamelling; annealing and normalizing; furnace muffles; radiant tubes; roller hearths; thermocouple sheaths; furnace fixtures; pusher trays; case-hardening boxes; gas-circulating fans; flare-stack tips; smoke elimination; safety valves; heavy-duty exhaust pipes; exhaust systems for diesel locomotives; exhaust valves; pottery cranks; gravity die casting; glass tools; paraffin heaters; furnace lips; and creep-testing machines. Illustrations of many of the components discussed in this connexion are included in the publication.

Thermal-Fatigue Cracking of Nickel-base-alloy Turbine Blading

R. A. SIGNORELLI, J. R. JOHNSTON and W. J. WATERS: 'Thermal-Stress Fatigue Cracking of Turbine Buckets Operated at 1700°F. in a Turbojet Engine with Long Periods of Operation Between Starts.'

Nat. Aeronautics and Space Administration, Tech. Note D-272, Feb. 1960; 22 pp.

In a previous investigation, turbine blades produced from five nickel-base high-temperature alloys were operated at 1700°F. (925°C.) in a turbojet engine to determine (1) their resistance to thermal fatigue cracking, and (2) the mechanism by which cracks progress to complete fracture. Due to the high test temperature, the operation of the engine was repeatedly interrupted for maintenance purposes, resulting in frequent starts (and short periods of operating time between starts). The large number of thermal-stress fatigue cracks which occurred during the tests was attributed primarily to the frequency of the engine starts (see *N.A.S.A. Tech. Note D*-125: abstract in *Nickel Bulletin*, 1960, vol. 33, No. 4, p. 84). The results of another test programme indicated that introduction of rated-speed operation between engine starts markedly reduced the number of starts necessary to cause cracking in 'S-816' and, 'M-252' turbine blades (see abstract in *Nickel Bulletin* 1959, vol. 32, No. 8, p. 262). The investigation now reported was initiated, within the scope of a study of thermal-stress fatigue cracking of turbine blading in a J-47 engine operated at 1700°F. (925°C.), to establish the effects of lengthening the period of rated-speed operation between engine starts. The blades

tested were either investment-cast from the nickel-chromium-cobalt-base alloys 'Sel-1' and 'B & B' and the nickel-chromium-base alloy 'Inconel 713', or forged from the nickel-chromium-base alloy 'Udimet 500' (for compositions see table accompanying the first abstract referred to in this paragraph).

The engine was operated for repeated cycles of 15 minutes at rated speed and five minutes at idle speed (as in the tests described in *Tech. Note D*-125), but the time at rated speed between starts was increased from 1·4 to 11 hours.

Thermal-stress fatigue cracking occurred in some blades of each alloy group early in the test, and 48 to 100 per cent. of the blades of each group were cracked at the conclusion of the test (i.e., after 33 starts and 357 hours at rated speed). Only two blades, however, fractured during the test. In the case of all the alloys, the increase in the operating time between starts permitted substantial increases in accumulated rated-speed operating time before cracking occurred, and, compared with the results of the previous investigation of the same alloys, decreased the number of starts necessary for initiation of cracking in 'B & B' and 'Udimet 500' blading. In the case of 'Sel-1', 'B & B' and 'Udimet 500' blading, increasing the operating time between starts also had the effect of increasing the number of blades cracked for a given number of starts. The mode by which cracks progressed to fracture was the same as that noted in the previous investigation. Fractures occurred by mechanical-fatigue progression of thermal-stress-fatigue cracks.

Effects of Melting Practice and Aluminium Coating on the Performance of 'GMR-235' Turbine Blades

C. A. GYORGAK, J. R. JOHNSTON and J. W. WEETON: 'Effects of Melting Practice and Aluminium Coating on the Life of 'GMR-235' Buckets Operated at 1650°F. in a Turbojet Engine.'

Nat. Aeronautics and Space Administration, Tech. Note D-263, Mar. 1960; 44 pp.

Over the past few years the significant increases achieved in the high-temperature strength of nickel-base turbine-blading alloys have led to the initiation of tests, at the Lewis Research Center, designed to determine the feasibility of operating the newer alloys at higher turbine temperatures (see, for example, abstract of *N.A.S.A. Tech. Note D*-125 in *Nickel Bulletin*, 1960, vol. 33, No. 4, p. 84). Since the nickel-chromium-iron-molybdenum-base high-temperature alloy 'GMR-235' (designed for service at 1500°F. (815°C.)) appeared to offer promise of satisfactory service at 1650°F. (900°C.), and since variations in melting practice and heat-treatment appeared to improve its properties, the material was subjected to engine tests at this temperature.

The specific objectives of the investigation were: (1) to compare the life of vacuum-melted blades with that of air-melted blades; (2) to determine the effect of aluminium coating on the life and thermal-fatigue properties of vacuum-melted and air-melted blades; (3) to determine the effect of ageing on the life of air-melted blades.

Air-melted and vacuum-melted master heats were re-melted under an argon atmosphere, and blades were then investment-cast in moulds purged with argon. Blades from each master heat were coated with aluminium by dipping and subsequent diffusion heat-treatment. (Other, uncoated, blades were subjected to the same diffusion heat-treatment.) The blades were evaluated in a J33-9 engine operating under cyclic conditions (a single cycle consisted of 15 minutes at rated speed (11,500 r.p.m.) followed by five minutes at idle speed (4,000 r.p.m.)).

When life was assessed on the basis of time to fracture, the results indicated that the life of vacuum-melted blades was more than twice that of air-melted blades. When performance was based on time to cracking by thermal fatigue, however, there did not appear to be any appreciable difference between vacuum-melted and air-melted blades. Aluminium coating appeared to improve resistance to thermal fatigue and to increase the time to fracture of the air-melted blades, but other factors involved in the fabrication and testing of the blades may, it is considered, have contributed to, or been responsible for, this improvement in performance. Ageing of air-melted blades did not significantly affect crack formation or time to fracture. Diffusion heat-treatment slightly decreased the thermal-fatigue resistance of uncoated vacuum-melted and air-melted blades and slightly increased the time to fracture of uncoated air-melted blades.

Influence of σ on the Properties of Austenitic Stainless Steels

R. F. HILLS and D. R. HARRIS: 'Sigma Phase in Austenitic Stainless Steels.'

Chemical and Process Engineering, 1960, vol. 41, Sept., pp. 391-6.

In the annealed condition the chromium-nickel steels of the A.I.S.I. 300 series are austenitic, and possess the ductility necessary for use in high-temperature applications. When, however, they are re-heated for long periods in the temperature range 550°-970°C., there is risk of formation of σ (a hard brittle non-magnetic phase) with consequent deleterious effects on ductility. In this paper the authors review the data available on (1) the properties of sigma, and (2) the effect of the phase on the properties of austenitic steels.

The review (which is based on a *bibliography* of 41 items) is in six main sections. The first is concerned with the factors involved in the formation of σ (e.g., temperature, and the composition and condition of the steel), and with discussion of work reported on the formation of σ from ferrite and from austenite. The five remaining sections cover the influence of σ formation on, respectively, room-temperature tensile and impact properties, elevated-temperature tensile ductility and impact properties, creep properties, thermal fatigue, and corrosion-resistance. Data culled from the literature are tabulated in illustration of the points raised in the text.

Influence of Silicon and Aluminium on the Stability of Sigma Phases

See abstract on p. 304.

Comparison of Embrittlement in Austenitic and Ferritic Steels

R. CASTRO and A. GUEUSSIER: 'Contribution to the Study of Embrittlement in Special Steels: Similarities Between Different Types of Embrittlement Observed in Ferritic and Austenitic Steels.'

Revue de Métallurgie, 1960, vol. 57, Aug., pp. 715-24.

In a previous investigation, the authors demonstrated that the low-temperature (—180°C.) impact-resistance of austenitic stainless steels was adversely affected when the steels were subjected to temperatures conducive to carbide precipitation. Moreover deformation of the steels at such temperature was found to induce hot brittleness, due to precipitation of carbides during deformation (*ibid.*, 1958, vol. 55, pp. 107-32). Since temper embrittlement of thermally-hardenable ferritic steels has been frequently attributed to precipitation, the study now described was undertaken to establish: (1) whether contaminant or addition elements known to promote temper embrittlement would have the effect of promoting low-temperature brittleness in austenitic steels; (2) whether the embrittlement occurring during deformation of austenitic steels in the temperature range conducive to formation of embrittling precipitates would occur also in ferritic steels deformed in the temperature range associated with temper embrittlement.

In the experiments carried out in connexion with the first objective, a study was made of the influence of phosphorus, arsenic, antimony and boron on the low-temperature impact strength of 17-12 and 16-16 chromium-nickel austenitic steels held at temperatures in the range 500°-1000°C. Notch-impact tests were carried out at —180°C. In the second phase of the study, stress-rupture tests were conducted, at temperatures in the range 500°-650°C., on four heats of steel (see below) quenched from 1200°C. and tempered for two hours at 650°C.

Steel	C %	Si %	Mn %	Ni %	Cr %	Mo %	P %
A	0·235	0·41	0·51	1·52	0·05	—	0·017
B	0·230	0·63	0·63	1·42	1·59	—	0·019
C	0·255	0·47	0·54	1·42	1·36	0·26	0·020
D	0·276	0·39	1·74	1·33	0·04	—	0·018

The data presented show that exposure to the appropriate temperature range can decrease the capacity of both types of steel to deform at the test temperature, an effect which, however, necessitates the application of lower rates of deformation in the case of the ferritic steels.

In both cases, the embrittling processes induce pronounced embrittlement in impact tests at temperatures in the region of the ductile/brittle transition, and tend to raise the transition temperature.

As in the case of the austenitic steels, in which embrittlement during hot deformation and that observed at −180°C. after sensitization appear to have a common cause, it is suggested that in ferritic steels temper embrittlement and embrittlement during long periods of creep are equally two manifestations of the same phenomenon in different regions of temperature.

Phosphorus, antimony and arsenic, which are known to promote temper embrittlement in ferritic steels, were found also to increase the embrittlement of austenitic steels at very low temperatures following quenching and tempering. Small additions of boron were, however, found to be beneficial, in that they reduced tendency to embrittlement.

The prior heat-treatment (and, in particular, increase in the quench temperature) seemed to have a similar influence on the embrittlement of the two types of steel.

The results of this and the previous investigation are regarded as favouring theories of temper embrittlement in which carbon and its compounds are assigned a major rôle.

Resistance of Nickel-containing Alloys and Steels to Hydrogen Embrittlement

J. E. SRAWLEY: 'Hydrogen-Embrittlement Susceptibility of Some Steels and Non-Ferrous Alloys.'

U.S. Naval Research Laboratory, Report 5392, Oct. 19, 1959; 25 pp.

The embrittlement of low-alloy high-strength steels by hydrogen assimilated during pickling or electroplating has been the subject of extensive studies during recent years. For the most part, these studies have been concerned with A.I.S.I. Type 4340 nickel-chromium-molybdenum low-alloy steel, which is widely used in the aircraft industry and which has been subject to failure by delayed fracture. One study, carried out to compare the behaviour of a number of commercial high-strength steels which are competitive with the A.I.S.I. Type 4340 grade in high-stress aircraft applications, has indicated that steels with relatively high silicon content offer some advantage (see *W.A.D.C. Tech. Report* 56-395: abstracts in *Nickel Bulletin*, 1958, vol. 31, No. 8, pp. 225-6). On the assumption that it would be of interest to evaluate a wider variety of materials (as a means of widening the range of comparative data on susceptibility to hydrogen embrittlement), the author undertook a test programme designed to throw light on the phenomenon of delayed fracture under constant load.

The ratio of the lowest nominal stress at which a hydrogen-charged notched tensile specimen fractured within 100 hours ('static-fatigue limit') to the notch tensile strength of the uncharged material was employed as a criterion of susceptibility. The specimens were very severely cathodically charged with hydrogen (24 hours at 0·5 amp./in.^{2}) to ensure detection of even a slight degree of susceptibility

to embrittlement. The following materials were selected for study: A.I.S.I. 52100 high-carbon chromium steel; A.I.S.I. 4340 nickel-chromium-molybdenum steel; A.I.S.I. 4130 chromium-molybdenum steel; A.I.S.I. 1020 carbon steel; 'Armco iron'; malleable cast iron; A.I.S.I. Type 410 and 422 chromium stainless steels; three grades of chromium-nickel precipitation-hardenable stainless steel; manganese-chromium-nitrogen austenitic steel; Type 304 chromium-nickel stainless steel; 'Monel'; 'K Monel'; 'Inconel'; copper-beryllium alloys; bronze; manganese bronze; aluminium bronze; beta brass; and an aluminium alloy. The condition in which the materials were tested varied (some were hot-worked or cold-worked, others were heat-treated before testing).

The data recorded by the author are supplemented by photomicrographs illustrating the types of fracture observed.

With the exception of the A.I.S.I. 1020 steel and the cold-rolled austenitic manganese-chromium-nitrogen steel (which exhibited moderate susceptibility), all the steels with hardnesses higher than Rockwell C30 were found to be very susceptible to embrittlement. The only steel found to show no susceptibility was cold-rolled Type 304 chromium-nickel stainless steel. The straight-chromium hardenable stainless steels were particularly susceptible to embrittlement, and Type 410 retained its high susceptibility down to a hardness of Rockwell C21. The low-alloy steels were less susceptible in the low hardness range.

None of the non-ferrous alloys was shown to be appreciably susceptible to hydrogen embrittlement (beta brass was found to be susceptible to delayed fracture under sustained constant load whether charged with hydrogen or not).

A general feature of the results was that the delay time to failure was usually short compared with other published data, a finding which is explained in terms of the effects of severe and prolonged charging with hydrogen. The delay time to failure is governed by the time required for hydrogen to diffuse in sufficient quantity to the region of plastic strain around the notch or crack tip: a high concentration of hydrogen throughout the specimens would thus tend to reduce the delay time.

Influence of Heat-Treatment on the Properties of '17-7 P.H.'

N. J. CARWILE and S. J. ROSENBERG: 'A Study of '17-7 P.H.' Stainless Steel.'

Wright Air Development Center, Tech. Report 58-653, June 1959; 36 pp.

The experiments reported were conducted with a quadruple aim: (1) to evaluate the mechanical properties of '17-7 P.H.' steel as a function of heat-treatment, and, hence, to establish the heat-treatment associated with optimum mechanical properties at temperatures in the range 70°-800°F. (20°-425°C.); (2) to determine the effects, on the mechanical properties of the steel, of long-time exposure (with or without load) at 600° and 800°F. (315° and 425°C.); (3) to identify the precipitation-hardening compound; (4) to gain information on the influence of nitrogen on the properties of the steel.

The composition of the steel tested was as follows: carbon 0·07, silicon 0·24, manganese 0·5, phosphorus 0·024, sulphur 0·014, chromium 17, nickel 7·2, aluminium 1·38, molybdenum 0·2, nitrogen 0·033, titanium 0·05, per cent. In the initial phase of the investigation, impact properties at room temperature, 600°F. and 800°F. were studied as a function of the following variations in heat-treatment: (*a*) solution-annealing at temperatures in the range 1700°-2000°F. (925°-1095°C.); (*b*) transforming at temperatures in the range 1200°-1600°F. (650°-870°C.); (*c*) precipitation-hardening at temperatures in the range 850°-1200°F. (455°-650°C.). The effect of refrigeration after transformation (to complete the transformation of austenite to martensite and, thereby, to increase the strength of the material) and the effect of time at ageing temperature were also investigated. Heat-treatments selected on the basis of the results obtained were then applied to specimens which were subsequently subjected to short-time tensile tests and stress-rupture tests at 600° and 800°F. (315° and 425°C.).

In view of reports that '17-7 P.H.' became embrittled after long-time exposure at moderately elevated temperatures, phase (2) of the test programme was initiated to determine the cause of, and methods of preventing or eliminating, such brittleness. Concurrently, a study of the structure of '17-7 P.H.' was to be carried out, by metallographic and X-ray techniques, to determine the precipitation-hardening compound.

Because of the marked stabilizing effect that nitrogen has upon austenite, it was decided in phase (4), to study the influence of the element at contents limited to about 0·1 per cent. maximum.

Optimum mechanical properties at room temperature were obtained by a heat-treatment which differed from the TH1050* treatment recommended by the manufacturers only in the transformation temperature (1350°F.: 735°C.). The most satisfactory elevated-temperature tensile and stress-rupture properties were obtained by application of the TH950† treatment.

Phase (2) of the study showed that a definite embrittlement occurred when the steel was subjected, in either the TH950 or TH1050 condition, with or without stress, to prolonged exposure at 800°F. (425°C.). It was found, however, that the original properties could be virtually restored by re-ageing.

Although in phase (3) extensive metallographic and X-ray examinations were carried out to throw light on the ageing mechanism and the precipitation-hardening compound, no definite conclusions were reached.

The nitrogen-containing steels studied were subjected to the normal TH950 and TH1050 treatments

* Solution annealed for ½ hour at 1950°F. (1065°C.), air-cooled; transformed for 1½ hours at 1400°F. (760°C.), air-cooled; aged for 1½ hours at 1050°F. (565°C.), air-cooled.

† As for TH1050, except that the final ageing is carried out at 950°F. (510°C.).

prior to tensile testing. The results obtained within the restricted limits of the investigation were rather erratic and showed no definite pattern. The strength values were low in comparison with those obtained with the commercial '17-7 P.H.' steel, a result which is considered possibly to be a reflection of the stabilizing effect of nitrogen upon austenite.

Heat-Treatment of High-Strength Steels for Airframe Applications

R. J. FIORENTINO, D. B. ROACH and A. M. HALL: 'Heat-Treatment of High-Strength Steels for Airframe Applications.'

Defense Metals Information Center, Battelle Memorial Inst., Report 119, Nov. 27, 1959; 94 pp.+ appendices.

In the heat-treatment of high-strength steels for use in aeronautical applications, the procedures long established in other industries do not satisfy the demands of the aircraft and missile manufacturers for much greater control over each stage of the heat-treatment. De-carburization must, for example, be held to a minimum (in some cases de-carburization, like carbon and nitrogen pick-up, must be completely prevented), warping must be avoided or minimized, and the dimensional changes that occur during heat-treatment must be compensated. In some instances, special heat-treatments have had to be devised to improve the workability, machinability or weldability of the newer high-strength materials, and the hardening and tempering cycle of the treatment must be such as consistently to result in the desired properties. The heat-treating practices used by many of the aircraft and missile manufacturers frequently differ from those recommended by the steel producers, and very often from those used by other consumers. Since some of the practices developed by the consumer were believed to represent significant improvements in the art of heat-treating, a survey of the current heat-treating practices and related problems appeared worthwhile. A substantial proportion of the information published in this memorandum (which presents the results of such a survey) was acquired in conference or correspondence with four steel producers and 24 consumers. This information was then augmented by suppliers' data sheets and by a review of the published literature.

Heat-treatment of seven classes of high-strength steel is covered by the survey: (1) low-alloy hardenable engineering steels; (2) hot-work die steels; (3) martensitic stainless steels; (4) martensitic precipitation-hardenable stainless steels; (5) semi-austenitic precipitation-hardenable stainless steels; (6) austenitic precipitation-hardenable stainless steels; and (7) cold-rolled austenitic stainless steels. The review is in seven sections (one for each grade of steel), and the information and data in each are presented under the same headings and sub-headings: Types, Uses and Illustrative Heat-Treatments; Current Practices and Problems (As-Received Material; Fabrication and Heat-Treatment; Atmospheres and Protective Coatings; Cleaning and De-scaling).

Resistance of Stainless Steel and 'Nimonic' Alloys to Thermal Shock

F. EICHHORN: 'The Thermal-Shock Behaviour of Steels and High-Temperature Materials.'

Stahl u. Eisen, 1960, vol. 80, Sept. 15, pp. 1275-83.

The author gives details of a test apparatus designed to establish the susceptibility of metallic materials to cracking under conditions involving repeated exposure to thermal shock. A narrow circumferential zone at the edge of a cylindrical specimen of the alloy or steel under investigation is repeatedly heated inductively by eddy currents of medium frequency, and, during testing, cooling water is passed through the specimen (inner diameter 10 mm.; outer diameter 36 mm.), so that the material is subjected to rapid temperature cycling. Resistance to thermal shock is assessed in terms of the number of cycles which the specimen is capable of withstanding before the occurrence of a macroscopic crack.

In illustration of the value of, and the procedures used in, the test, the author presents and discusses the data obtained from tests on specimens of the following materials: carbon steel, chromium-molybdenum low-alloy steel, 18-8-Ti stainless steel, and the nickel-base high-temperature alloys 'Nimonic 75', 'Nimonic 80A', 'Nimonic 90' and 'Nimonic 95'.

The behaviour of these materials under thermal-shock conditions was influenced both by the maximum test temperature and the number of temperature cycles to which they were subjected. In all cases, the number of cycles necessary for failure decreased with increase in the peak temperature of the cycle, but the resistance of the nickel-base alloys to thermal shock was far superior to that of the steels tested. (When cycled to 920°C. the alloys differed greatly in their thermal-shock behaviour.)

Due to the number of variables involved, the author finds it difficult to evaluate with certainty the thermal-shock behaviour of the materials from any one point of view. The test procedure described is nevertheless considered suitable for use in determining the behaviour, under reproducible conditions, of materials of similar type, with approximately similar electromagnetic properties, during exposure to repeated rapid local heating.

Materials for High-Temperature Compression Springs

J. M. THORNTON: 'High-Temperature Alloys for Compression Springs.'

Materials in Design Engineering, 1960, vol. 52, Aug., pp. 111-15.

Compression springs are used widely in almost every industry, finding their most extensive and important application in safety valves. In this article, the author summarizes the results of work carried out to compare the suitability of various heat-resisting materials for use in compression springs intended for such high-temperature service.

The following materials were evaluated: the nickel-base alloys 'Inconel' and 'Inconel X'; the chromium-nickel precipitation-hardenable steels '17-4 P.H.' and '17-7 P.H.'; 2 per cent., 9 per cent., and 18 per

cent. tungsten steels; the cobalt-base alloy 'Haynes 25'; and Type 302 18-8 stainless steel. In the investigation, designed to determine load-loss at high temperature, specimens of hot- and cold-wound springs were subjected, for 168 hours at 700°F. (370°C.), to a stress of 77,500 p.s.i. (34·5 t.s.i.: 54·5 kg./mm.²). Full details are given of composition, heat-treatments, specimen design and test procedures, and the characteristics and relative cost of each material tested are compared.

The results of the load-loss tests are reproduced in the table below.

	Springs	Load Loss %
Hot-Wound	'17-4 P.H.'	17·7-18·9
	'Inconel X'	2·7 - 8·3
	9% Tungsten Steel	12·5-27·1
	2% Tungsten Steel	14·3-19·1
	18% Tungsten Steel	15·7-31·0
Cold-Wound	'Haynes 25'	0·89-1·78
	'Inconel X'	3·1-4·9
	9% Tungsten Steel	11·5-12·0
	'Inconel'	18·7-19·1
	'17-7 P.H.'	23·5-27·1
	Type 302 Steel	28·9

On the basis of these data, the author concludes that, in so far as relaxation at high temperatures and corrosion-resistance are concerned, 'Inconel X' is the most satisfactory material for hot-wound springs. Of the cold-wound springs, 'Haynes 25' appeared to exhibit the most satisfactory resistance to high-temperature relaxation, though it is considered that a longer test might have favoured 'Inconel X'.

Bristol Type 188 Stainless-Steel Supersonic Research Aircraft

'Stainless Steel Supersonic Aircraft: Builder and Steelmaker Co-operate.'

Metallurgia, 1960, vol. 62, Sept., pp. 110-14.

The Bristol Type 188 supersonic research aircraft is designed to fly at speed exceeding 1500 m.p.h., i.e., at speeds at which, under the combined effects of kinetic heating and the heat generated by the engines, the structure of the aircraft will be exposed to temperatures in the region of 250°C. It was decided therefore that the Type 188 should be of welded stainless-steel construction, and that the particular grade of steel used would be selected on the basis of its satisfying the following requirements: ready availability in large-size sheets conforming to the surface finish and tolerances laid down; possession of an optimum combination of mechanical properties (e.g., high modulus of elasticity, high strength, adequate ductility); reasonable uniformity of mechanical properties as between longitudinal and transverse directions of loading; simplicity of heat-treatment; and satisfactory properties at the temperatures involved in service. In the present article reference is made to the close co-operation between Bristol Aircraft, Ltd., and Firth-Vickers Stainless Steels, Ltd., which marked the selection and supply of the materials for the major structural parts of the aircraft.

Of the materials considered, the titanium-stabilized 18-8 chromium-nickel steel 'Firth Vickers F.D.P.' was chosen for the major outside envelope of the fuselage structure (which involved double-curvature forming). 'F.V. 448', a complex 12 per cent. chromium stainless steel, though rejected for this application because of difficulties entailed in producing flat sheets of a sufficient size, exhibited attractive mechanical properties and was used in other applications. The factors involved in the provision of stainless steels suitable for use in the form of sheet, plate, bar, forgings, fasteners and tubes are reviewed.

Carburization and De-Carburization of Iron-Nickel Alloys

See abstract on p. 306.

Evaluation of the Salt-Spray Corrosion Test

A. KUTZELNIGG: 'The Salt-Spray Test.'

Werkstoffe u. Korrosion, 1960, vol. 11, Sept., pp. 547-51.

In this assessment of the rôle of the salt-spray test in corrosion testing, the author draws attention to the various German, American, British, French and Swiss standards covering the test and discusses 22 variables stated to influence the results obtained.

He comes to the conclusion that the test is principally suitable for revealing coarse flaws in metallic coatings. Coatings which fail the test will generally fail prematurely during atmospheric exposure, but those that pass the test must not, *ipso facto*, be regarded as satisfactorily corrosion-resistant. In assessing corrosion-resistance the salt-spray test should be used only when its results have been correlated with corrosion behaviour under the actual service conditions.

Developments in Corrosion-Resistant Materials

G. L. SWALES: 'Developments in Corrosion-Resistan Materials.'

Published in 'Corrosion Problems of the Petroleum Industry,' pp. 184-210; disc., pp. 226-32.

Soc. Chemical Industry, Monograph No. 10, 1960; 235 pp.

The past decade has seen many important advances both in the development of new corrosion-resisting materials and in the improvement of established types of alloy and their modification for specific applications. A considerable proportion of the applied research in this field has been directed to the special requirements of nuclear engineering, and to the appraisal of the resistance of existing and newly developed materials to corrosion by liquid metals, fused

halides, high-temperature water and the aggressive environments encountered in the chemical processing of nuclear fuel. There have, however, been numerous important, if perhaps less spectacular, developments in materials for specific and general applications in the chemical, petroleum and marine fields. This paper is concerned with some of these last applications, selected as being of interest in the production, transportation, refining and chemical-processing phases of the petroleum industry. It is emphasized that many of the important developments in this field do not necessarily involve better corrosion-resistance, since considerable importance can attach also to development of better mechanical properties, to the improvement of fabrication characteristics and to the general adaptability of established classes of corrosion-resistant metals: such modifications can markedly affect the scope of their use and design economics, and items which fall into these categories are also considered.

Developments in low-alloy steels are reviewed in sections covering chromium-molybdenum-aluminium steel for oil- and gas-well tubing and steels for off-shore structures. The advantages offered by the martensitic, semi-austenitic and austenitic precipitation-hardenable stainless steels are considered, and attention is then drawn to the properties and uses of ferritic, pearlitic and austenitic grades of spheroidal-graphite cast iron.

Developments in nickel-base alloys are discussed in sections relating to, respectively, nickel-molybdenum alloys, nickel-chromium-molybdenum-iron alloys, and a 65-35 nickel-chromium alloy. Subsequent sections are concerned with high-temperature materials (specifically, those used for gas-turbine components, and for furnace tubes and tube supports), copper-base alloys (gunmetals and high-tensile aluminium bronzes), and titanium, zirconium, tantalum and niobium. The paper closes with a brief discussion of developments in the fabrication of corrosion-resistant materials.

Throughout the review, the points raised by the author are frequently supplemented or illustrated by photomicrographs and tabular and graphical data.

Experience in the Application of Corrosion-Resisting Steels

J. CLAAS and H. GRÄFEN: 'Developments and Experience in the Application of Corrosion-Resisting Steels.'

Werkstoffe u. Korrosion, 1960, vol. 11, Sept., pp. 529–47.

A great deal of information is available on the iron-base materials used in the chemical industry, and their advantages and limitations in such applications are well established. Since any further improvement in the corrosion-resistance of the steels employed in this respect is likely to be limited, development and research activity is tending to concentrate on enhancing other properties which are likely to increase the utility of the steels in specialized fields of application (e.g., weldability, workability, heat-resistance, low-temperature ductility, hardness, etc.). In this paper, in which reference is made to a *bibliography* of 25 items, the authors review the progress which has been made in this direction, and consider the experience which has been gained in the application of relevant materials.

The review opens with a description of corrosion failures in 13 and 17 per cent. chromium low-carbon stainless steels, which, in view of their unexpectedness, are deemed worthy of discussion.

Heat- and corrosion-resisting grades of stainless steel form the subjects of the next section. The authors reveiw the mechanical properties and corrosion-resistance of 12-1 chromium-molybdenum, chromium-molybdenum-vanadium and chromium-molybdenum-vanadium-tungsten ferritic steels, and of 16-13 and 16-16 chromium-nickel-niobium austenitic steels, and particular attention is given to data throwing light on the influence of high-temperature service on the susceptibility of the austenitic steels to intergranular or stress corrosion.

A survey of the heat-treatment, mechanical properties and corrosion-resistance of martensitic, semi-austenitic and austenitic grades of precipitation-hardenable stainless steel is followed by a section on the chromium-manganese-nickel stainless steels (in which low-temperature properties and susceptibility to stress corrosion form the main subjects of discussion), and finally consideration is given to the factors (including the use of high-nickel electrodes) involved in the welding of ferritic steel to austenitic steel.

Materials for Sea-Water Applications

F. W. FINK: 'Metals for Sea-Water Service.'

Industrial and Engineering Chemistry, 1960, vol. 52, Sept., pp. 56a–8a.

In the introductory section of this short article the author refers to the factors which should be taken into account in considering the suitability of a metallic material (and the design of equipment) for use in applications involving exposure to sea water. Marine fouling, crevice corrosion, impingement attack, cavitation and galvanic corrosion are briefly considered in this connexion.

The remainder of the article comprises notes evaluating the relative suitability, for sea-water applications, of the following types of material: steel; cast and wrought iron; aluminium and its alloys; copper-base alloys; cupro-nickels; the nickel-base alloy 'Hastelloy C'; titanium.

Resistance of Nickel-Plated Materials to Corrosion by Domestic Detergents

E. WAGNER: 'Corrosion-Resistance of Various Metals in Domestic Detergents.'

Seifen-Öle-Fette-Wachse, 1960, vol. 86, Jan. 20, pp. 25–30.

Metals used in the construction of washing machines

are subject to various degrees of corrosion in contact with detergent solutions. In the investigation described, the following materials were exposed, by way of evaluating their resistance in this respect, to the corrosive action of three different detergent solutions: zinc-coated steel sheet (galvanized or hot-dipped); copper sheet; dull-nickel-plated and bright-nickel-plated copper and brass sheet; copper and brass sheet plated with dull nickel+chromium; brass sheet plated with copper + dull nickel + chromium; aluminium-manganese alloys; and an aluminium-magnesium-silicon alloy.

No account was taken of the effects of the interaction of dirt and textiles with the metal surface, but full allowance was made for the other conditions involved in washing. The corrosion-resistance of the materials studied was assessed in tests involving exposure to each of three commercially available detergents: a self-active synthetic detergent (6 g./L.); a special washing-machine detergent free from sodium carbonate (5 g./L.); and a special washing-machine detergent containing sodium carbonate. During testing the solution was agitated by a stirrer. The temperature was raised to 95°C. over a period of 30 minutes, and the specimen was maintained at this temperature for 60 minutes. After removal of the washing solution, the specimen was rinsed for five minutes with water at 60°C. and dried. The change-in-weight was then determined. The data presented are discussed in relation to the influence, on the corrosion rate, of the time and temperature of exposure, the nature of the specimen surface, and the presence of galvanic couples.

All the materials tested suffered corrosive attack, zinc being the most, and the nickel- and nickel + chromium-plated specimens the least, severely corroded. The type of zinc coating (i.e., galvanized or hot-dipped) had no effect on the rate of corrosion. Corrosion of copper was severe, but nevertheless significantly less than that suffered by zinc in all three detergents studied.

The nature of the specimen surface had no significant influence on the corrosion rate. In the self-active and sodium-carbonate-containing reagents, galvanic coupling enhanced the corrosion of zinc and reduced that of copper. In the sodium-carbonate-free detergent, corrosion of zinc was reduced and that of copper increased.

Of the three detergents tested, the self-active reagent was the most, and the sodium-carbonate-free reagent the least, corrosive.

Corrosion Tests on Nickel-Plated Steels

See abstract on p. 303.

Influence of Nickel on the Susceptibility of Beta Brasses to Intercrystalline Cracking

See abstract on p. 304.

Production and Properties of 'Alloy 20' Stainless Steel

L. FINK: 'Alloy 20 Stainless Steel: Production and Mechanical Properties.'

Modern Castings, 1960, vol. 38, Sept., pp. 99–102.

'Alloy 20'*, a fully austenitic stainless steel developed to exhibit increased resistance to sulphuric acid, is susceptible not only to the hot-shortness associated with low-carbon fully austenitic chromium-nickel stainless steels when cast into sand moulds, but also to a particular type of hot-shortness which entails limiting the lead content to 0·002 max. per cent. and the total content of silicon+chromium to 4·5 per cent. Even when these precautions are taken, however, some heats of the steel have been found to be still sensitive to hot-shortness. In this article the author reports an investigation initiated to throw light on the factors involved in the problem.

Susceptibility to hot-shortness was assessed on the basis of the results of a test in which a keel block cast from the steel was heated, by an oxy-acetylene flame held at a fixed distance from the surface, to a temperature just below the solidus. The keel block was then cooled and examined for evidence of cracking.

In an attempt to find an addition element which would inhibit occurrence of hot-shortness, tests were made to determine the effects of, *inter alia*, niobium, 'Mischmetall' or vanadium. The vanadium was added *viâ* a proprietary addition alloy consisting of vanadium, titanium, aluminium, silicon, boron and iron, a combination which was found to minimize sensitivity to hot-shortness. The exact mechanism of this effect is not known, but the evidence available indicates that it may be the result of (1) more thorough deoxidation, (2) promotion of nucleation (which may produce a finer grain) by the addition elements, and/or (3) the increase in strength at the grain boundaries associated with the presence of the larger atoms of the vanadium and titanium.

In the concluding section of the article the author summarizes the results of a test programme conducted to establish the minimum mechanical properties of the steel. A statistical analysis of the results obtained on 118 heats demonstrated that, provided the carbon content is within the range 0·05–0·07, the following minimum values can be obtained: tensile strength, 60,000 p.s.i. (27 t.s.i.: 42 kg./mm.²); yield strength, 27,000 p.s.i. (12 t.s.i.: 19 kg./mm.²); elongation, 45 per cent.

High-Nickel Alloys for Fasteners

E. R. PATTON: 'Stopping Corrosion, High-Temperature and Shock Losses with High-Nickel-Alloy Fasteners.'

Fasteners, 1960, vol. 15, No. 1, pp. 7–11.

In many applications the suitability of a material for use as a fastener is governed by the degree to which it can satisfy one or more of such requirements

* Carbon 0·07 max., manganese 2·0 max., silicon 1·5 max., nickel 27·5–31·0, chromium 19·0–22·0, copper 3·0–3·5, molybdenum 1·8–2·5, per cent.

as corrosion-resistance, heat-resistance, high strength and toughness, hardness and abrasion-resistance, machinability, and non-magnetic properties or special electrical characteristics. In this article, the author draws attention to the advantages offered in this respect by the wide range of high-nickel alloys which are now commercially available. When properly selected, they can, it is stated, satisfy virtually any requirement involved in a specific fastener application.

Reference is made in particular to the properties offered by the following materials, and to the fastener applications for which they have proved suitable: 'Monel', 'Monel 403', 'K Monel', 'KR Monel', 'R Monel', 'Inconel', 'Inconel X', 'Incoloy', 'Incoloy 901', 'Ni-o-Nel', nickel, and low-carbon nickel. The greater part of the article is taken up by sections illustrating the use of nickel-base alloys as fastener materials in food processing, electronic applications, and applications involving exposure to marine environments, chemical corrosion or high temperatures. Brief reference is made to the fabrication of explosive rivets from low-carbon nickel.

'Inco-Weld A' Welding Electrode and Filler Wire

HENRY WIGGIN AND COMPANY, LTD.: ' 'Inco-Weld A' Welding Electrode and Filler Wire.'

Publn. 2048*, 1960; 11 pp.

In the past the problem of selecting a suitable filler material for welding dissimilar metals has often proved an insurmountable obstacle to the fabricator. For many years the general rule has been that the filler metal should match the higher alloy of the materials being joined, but, although this rule has proved satisfactory for some combinations, in many cases an undesirable deposit has resulted from the filler metal's being diluted with the lower-alloy basis metal. Welding experience has shown that a fully effective filler metal should exhibit the following properties: (1) high tolerance for dilution by such elements as iron, nickel, chromium and copper, without forming brittle or crack-sensitive alloys; (2) a moderate coefficient of thermal expansion; (3) ability to withstand high service temperatures over a long period without suffering such harmful effects as sigma-phase formation or carbon migration; (4) good oxidation- and corrosion-resistance; (5) high strength and ductility at high and low temperatures. 'Inco-Weld A' electrode and 'Inco-Weld A' filler wire were developed specifically to meet these requirements.

'Inco-Weld A' electrodes (designed for use with direct current, with the electrode connected to the positive side) are flux-coated, and are employed with the manual metal-arc welding processes. 'Inco-Weld A' filler wire, a bare wire supplied on spools and in straightened and cut lengths, is for use with either the inert-gas tungsten-arc or the inert-gas metal-arc processes. 'Inco-Weld A' wire deposits can be age-hardened (the wire should be used when joining combinations of age-hardenable materials), otherwise its properties are the same as those of the electrode.

This publication gives information on the use of the electrode and wire, and on the properties obtainable in the welds produced. Data derived from hardness surveys across, and from longitudinal bend tests and guided face- and root-bend tests on, welds produced in various combinations of dissimilar alloys and steels are tabulated. In other sections of the publication, data are given on the coefficient of thermal expansion of 'Inco-Weld A' wire and electrode, the stress-rupture strength of 'Inco-Weld A' weld metal, and the low-temperature impact properties of welds produced in 3½ per cent. and 9 per cent. nickel steels.

Evaluation of BP-85 'Inconel' Covered Electrodes for Use in Nuclear-Power Applications

G. F. MCKITTRICK and W. A. OWCZARSKI: 'Report on the Evaluation of BP-85 'Inconel'-type Covered Electrode.'

U.S. Atomic Energy Commission, Report KAPL-M-GFM-8, June 26, 1959; 18 pp.

The research programme described originated in the decision to use the nickel-base alloy 'Inconel' for applications in the D1G prototype naval nuclear-power plant requiring high-quality welding in all positions. With the covered welding electrodes currently available, weldments in 'Inconel' pipe could not be consistently made to the standards required because of defects, particularly porosity in welds produced in the overhead position. The manual tungsten inert-gas welding method, which could be employed to produce welds of the required standard, involved too slow a rate of deposition and was difficult to use where access to the weld was restricted. In the light of this situation, The International Nickel Company, Inc., undertook the development and production of a new 'Inconel' covered electrode capable of meeting the higher-quality standards required in radioactive systems. This electrode, tentatively designated BP-85, is for use in overlaying carbon steel, and in welding 'Inconel' to itself and 'Inconel' to dissimilar metals. The $\frac{5}{32}$-in. (0·225-cm.) and $\frac{1}{8}$-in. (0·3-cm.) sizes are intended to provide all-position electrodes for use in all applications except overlay cladding; the $\frac{5}{32}$-in. (0·375-cm.) size is intended as an all-position electrode for all applications; and the $\frac{3}{16}$-in. (0·45-cm.) and $\frac{1}{4}$-in. (0·6-cm.) sizes are intended only for down-hand and horizontal fillet positions. This report summarizes the data obtained in an evaluation of the electrode.

The evaluation programme comprised the following phases:

(1) The mechanical characteristics of the filler metal were determined using all-weld-metal tensile and guided transverse side-bend specimens taken from a series of transverse butt-welds. Specimens of the weld deposits were heat-treated to determine the effect of post-weld stress-relieving.

Down-hand-position joints were welded between 1-in.-thick plates of 'Inconel', between 'Inconel' and 304L stainless steel, and between 'Inconel' and carbon steel. Heavy section (2½-in.) joints of 'Inconel' to 'Inconel' and 'Inconel' to A.S.T.M. A 212 steel were

* *We shall be pleased to supply a free copy of this publication.*

also welded. Analysis of the weld deposit from the 'Inconel'/'Inconel' joint gave the following values: nickel 67, chromium 14·58, iron 7·98, manganese 7·25, niobium+tantalum 1·88, titanium 0·57, silicon 0·48, cobalt 0·08, carbon 0·042, sulphur 0·006, aluminium 0·004, per cent.

(2) The efficacy of the BP-85 electrode as a filler material for cladding carbon steel was demonstrated by deposition of a three-layer overlay $\frac{5}{16}$-in. thick. Bend tests were conducted on clad samples.

(3) The suitability of the electrode for use in welding pipe was verified in relation to the properties of welds in pipe of $5\frac{1}{2}$-in. outer diameter and $\frac{3}{4}$-in. wall.

(4) The resistance of BP-85 weld metal to stress-corrosion cracking was evaluated by tests involving exposure to boiling 42 per cent. magnesium chloride, boiler water at 500°F. (260°C.), or static primary water at 600°F. (315°C.).

The conclusions drawn from the results of the evaluation are given below:

'It is concluded BP-85 electrode is the best 'Inconel'-type covered electrode tested to date. With the proper deposit technique and electrode size, all-position welds can be consistently deposited to nuclear standards (NAVShip 250-292-2, Group I). The electrode has been found to be suitable for 'Inconel' to 'Inconel' welds, dissimilar-metal welds, and carbon-steel overlays.

'Cross-weld and all-weld-metal test results show the mechanical properties of the BP-85 filler metal exceed the corresponding minimum properties of 'Inconel', A212 carbon steel and Type 304L stainless-steel base metal. Both the overlay bend test and groove-weld bend tests have shown the filler metal to be resistant to fissuring and cracking, and superior in this respect to the other 'Inconel'-type covered electrodes. The BP-85 weld metal has not shown any hardening or embrittlement in the normal carbon-steel stress-relieving temperature range.

'Due to low deposition rates, the $\frac{3}{32}$-in. and $\frac{1}{8}$-in. electrode sizes are not recommended for weld overlaying; however, these sizes might be found advantageous for smaller repair welds. The $\frac{3}{32}$-in. and $\frac{1}{8}$-in. electrode sizes are the only sizes recommended for overhead welding, since the larger sizes result in poorer bead contour and slag entrapment in locations where it is difficult to remove.

'Stress-corrosion tests have shown the weld deposit resistant to the same degree as wrought 'Inconel'. Short-time static corrosion tests (300 hours) in water of D1G primary composition have indicated that the material has a comparable corrosion rate to stainless steel. Long-term corrosion rates comparable to the life of the plant are not as yet established. Since, with even a relatively low rate, the high manganese content might add considerably to the radioactive accessibility, it is recommended that the area of BP-85 filler metal exposed to primary coolant be limited.

'Future work on the BP-85 electrode filler metal includes determination of the effect of irradiation on mechanical properties, completion of static corrosion tests, dynamics loop corrosion tests, and additional post-weld heat-treatment studies.'

(A corresponding bare wire, designated BP-87 and for use with argon-shielded welding processes, is at present under evaluation by the same authority.)

Structure and Properties of Flash-Butt Welds in 'Nimonic' Alloys

F. A. BALL and D. R. THORNEYCROFT: 'The Structure and Properties of Flash-Butt Welds in 'Nimonic 75', '80A' and '90'.'

Welding and Metal Fabrication, 1960, vol. 28, Sept., pp. 362-7.

In gas-turbine construction (one of the fields of application in which the advantages offered by flash-butt-welded rings are receiving particular attention) rings of heat-resisting materials are often required for structural components and stiffeners of various kinds. The 'Nimonic' series of nickel-chromium-base high-temperature alloys are (in the form of extruded section, often available to near-finish dimensions) finding increasing application in this respect. The successful application of flash welding to 'Nimonic 75' is reflected in the satisfactory values obtained for tensile and stress-rupture properties, and, since the high-temperature properties of this alloy are not achieved by heat-treatment, it has the attraction of requiring no post-weld heat-treatment (other than that for stress-relieving, when this is considered desirable). The properties of 'Nimonic 80A' and the other wrought 'Nimonic' alloys are, on the other hand, governed by the heat-treatment applied, and it would be expected therefore that the heating and deformation involved in the welding operation would influence the properties exhibited by the welded alloy (preliminary tests have, however, indicated that, when subjected to the conventional heat-treatment, flash-butt-welded joints in 'Nimonic 80A' and 'Nimonic 90' develop mechanical properties similar to those of the wrought grades). In the present paper the authors summarize the results of a study of the influence of heat-treatment on the properties of welds in extruded bars of thick section. Observations on the metallurgical structures involved are reported, and data available on the influence of weld upset distance on properties and microstructure are presented and discussed.

The paper includes graphical and tabular data on tensile, stress-rupture and (to a limited extent) fatigue properties of flash-butt-welded joints. On the basis of these, and the hardness-traverse curves and photomicrographs also included in the paper, the authors conclude that the properties of flash-welded joints in the 'Nimonic' alloys can be comparable with those of wrought material.

Of primary consideration is the need for adequate upset in the welding operation (to ensure consistent properties) and, in the case of the precipitation-hardening alloys 'Nimonic 80A' and 'Nimonic 90', application of a full heat-treatment after welding. The results indicate that it may be possible to reduce the time of the first stage of the treatment from 8 hours to 1 hour, but this point is considered to need further study.

Welding of Wrought Nickel-base Age-Hardenable Alloys

W. J. LEPKOWSKI and R. E. MONROE: 'The Welding of Wrought Age-Hardenable Nickel-base Alloys for Service at Elevated Temperatures.'

Defense Metals Information Center, Battelle Memorial Inst., Memorandum 38, Nov. 25, 1959; 17 pp.

In this memorandum the authors review, on the basis of a *bibliography* of 39 items, the information available on the fusion welding and resistance welding of nickel-base age-hardenable high-temperature alloys. The points raised in the review are illustrated by data relating to 'Inconel X', 'Inconel W', 'Inconel 700', 'Inconel 702', 'Incoloy 901', 'Nimonic 80A', 'Nimonic 90', 'M-252', 'René 41', 'Waspaloy', 'Udimet 500', 'Udimet 600', 'R-235', or 'Hastelloy X'. While specific data on welding variables are not available for all these alloys, and the values reported do not cover all the possible conditions that may be encountered in welding, the information presented should, it is considered, serve as a guide to the selection and use of appropriate welding processes and procedures, 'with reasonable assurance that what has been found to apply to one alloy will apply also to others in the same class'.

The memorandum is in three sections. In the first, attention is briefly drawn to heat-treatment procedures, metallurgical characteristics and other factors which must be taken into account in welding such high-temperature alloys; the second section covers fusion-welding processes and techniques; the last refers to the procedures and conditions recommended for resistance welding.

Heat-Affected-Zone Cracking in Austenitic-Steel Weldments

R. J. TRUMAN and H. W. KIRKBY: 'Some Ductility Aspects of 18-12-1Nb Steel.'

Jnl. Iron and Steel Inst., 1960, vol. 196, Oct., pp. 180–8.

In steam-power plants severe cracking troubles have been experienced with weldments produced in 18-12-1Nb (A.I.S.I. Type 347) steel under a high degree of mechanical restraint. In most of the cases reported, cracking occurred in the heat-affected zone of the weld, and appeared to initiate at, or near, the junction of the parent metal and the weld. Rupture tests on specimens taken aeross welded joints in 18-12-1Nb steel have also indicated a tendency to failure similar to that encountered in service, and, in addition, cracking identical with service failures has been produced, under laboratory conditions, during post-weld stress-relief treatments. The finding that 18-12-1Nb steel exhibited a marked degree of hot-shortness when tested at temperatures of 2400°-2500°F. (1315°-1370°C.), and that this low ductility persisted on cooling to 2200°F. (1205°C.) following initial heating to 2400°-2500°F., does not, in the present authors' opinion, explain why laboratory creep-rupture specimens, taken from 18-12-1Nb weldments stress-relieved at 750°C., fractured in the heat-affected zone practically at the weld junction when tested at 650°C., but in the parent metal, well away from the weld junction, when previously stress-relieved at 850°C. or 1050°C. The data from which the last conclusions were drawn are outlined in the initial section of the present paper.

In the remainder of the paper the authors present and discuss the results of short-time tensile tests which, since the creep-rupture tests had indicated that cracking almost invariably occurred in the heat-affected zone, were carried out, at temperatures in the range 600°-1050°C., on 18-12-1Nb steel solution-treated at temperatures (1050°, 1150°, 1250° and 1350°C.) intended to simulate the thermal conditions obtaining in the heat-affected zones of weldments. Most of the test pieces were subjected to metallographic examination.

The ductility curves derived from these tests indicate the existence of two regions of low tensile ductility: one in the region of 850°C., the other in the region of 1100°C. The occurrence of the low-ductility zone at 850°C. is attributed to strain-induced precipitation of niobium carbide, and it is postulated that such a mechanism could explain the 'conditioning' of the weld junction in 18-12-1Nb steel, thereby rendering the steel highly susceptible to cracking. The second ductility trough at 1100°C. is not considered to have an important bearing on this particular problem.

Influence of Heat-Treatment and Microstructure on the High-Temperature Ductility of Austenitic Steels

K. J. IRVINE, J. D. MURRAY and F. B. PICKERING: 'The Effect of Heat-Treatment and Microstructure on the High-Temperature Ductility of 18%Cr-12%Ni-1%Nb Steels.'

Jnl Iron and Steel Inst., 1960, vol. 196, Oct., pp. 166–79.

Austenitic stainless steels containing niobium have been extensively used in the U.K. and the U.S.A. for high-temperature applications in steam-power plant. In both countries, however, difficulties have arisen during service, which have been attributed to the fact that, while the steels exhibit high rupture strength, they tend to have low rupture ductilities after long periods of testing, a characteristic which is invariably associated with an intergranular type of failure. It has also been found that this type of steel exhibits low levels of ductility during hot bending at certain temperatures (dependent upon the solution-treatment conditions). Consideration of this behaviour, and of reports of weld cracking in the heat-affected zone, led to the suggestion that the trouble might be the result of carbide precipitation caused by the thermal conditions to which the heat-affected zone is exposed. It was decided therefore to investigate the mechanism of low ductility by studying the effect of heat-treatment and strain on the carbide-precipitation processes in 18-8-1Nb steel, and by correlating the resultant microstructures with the properties of the steel.

Three methods were employed to investigate the ductility phenomena: (1) A study was made of a series of specimens which, after solution-treatment at 1050°C., were rupture tested at temperatures in the range 550°–700°C. for times up to 30,000 hours; (2) A study was made of specimens solution-treated at various temperatures and then bent at different temperatures in the range 560°–950°C.; (3) With a view to establishing the influence, on tensile ductility, of both solution-treatment temperature and the test temperature, tensile tests were carried out, at various temperatures in the range 700°–900°C., on specimens previously subjected to different solution-treatments. After rupture and bend testing, specimens were subjected to metallographic examination by optical and electron microscropy.

The extensive experimental data presented are supplemented by photomicrographs illustrating the microstructures of the specimens tested in the various phases of the study. On the basis of these data, the authors draw conclusions which they summarize as follows:

'1. Precipitation of NbC can occur rapidly from the matrix of 18-12-1Nb austenitic steels under the activation of plastic strain.

'2. In the rupture tests, this precipitation produces a fine precipitate of NbC, at temperatures of 550°–700°C., when the applied stress is sufficient to exceed the 0·1 per cent. proof stress and plastic deformation occurs during loading. At stresses lower than the 0·1 per cent. proof stress, any precipitation of NbC occurs over much longer times, and is formed in a very much coarser dispersion.

'3. In the bend tests, the strained regions of the specimens showed a much heavier precipitation of NbC than did the unstrained regions, and, with increasing bend-test temperature, the size of the precipitated NbC particles became larger.

'4. The loss of ductility in both rupture- and bend-test specimens was invariably associated with a fine general precipitate of NbC which caused hardening of the matrix, so that the grains became more resistant to creep deformation and the plastic deformation was largely thrown on to the grain-boundary regions. Under these conditions, grain-boundary sliding and intergranular fracture resulted, with a marked loss of ductility.

'5. The results of both bend and tensile tests showed that the loss of ductility was more pronounced, and occurred over a wider temperature range, as the solution-treatment temperature increased, because of the larger amount of niobium available in solution for precipitation as NbC.

'6. The conditions necessary for a decreased ductility to be observed are: that there should be fairly large amounts of NbC available for precipitation, that some plastic deformation should be applied during the precipitation process, and that the general dispersion of the precipitated NbC should cause marked strengthening of the matrix. If the NbC is overaged and does not strengthen the matrix, as occurs in very-long-time rupture tests, or in bend tests above 850°C., the ductility is not adversely affected.

'7. While grain-boundary denudation is a contributing factor to the loss of ductility, it is not an essential feature, since, if the matrix precipitate is coarse and overaged, the ductility will be high despite grain-boundary denudation.

'8. It is possible to improve ductility, especially in bend and tensile tests, by ageing at 900°C. after solution-treatment but before testing. This precipitates coarse NbC particles, and lowers the amount of NbC in solution to such an extent that, on subsequent testing in the normal temperature range for low ductility, there is insufficient NbC precipitated to give the effect. This prior ageing treatment, however, will lower the strength, and the material must be re-solution-treated before service. Such an ageing treatment, however, would enable fabrication to be carried out with less risk of cracking.

'9. It has been shown that NbC can precipitate on dislocations, and in that condition, which is usually associated with warm working, it is believed that the optimum effect is exerted in improving the creep strength.

'10. A suggestion has been made that the heat-affected-zone cracking in welds of high degrees of restraint is associated with strain-induced precipitation.'

Heat-Affected-Zone Cracking in Welded Austenitic Steels

R. N. YOUNGER and R. G. BAKER: 'Heat-Affected-Zone Cracking in Welded High-Temperature Austenitic Steels.'

Jnl. Iron and Steel Inst., 1960, vol. 196, Oct., pp. 188–94.

The work described was initiated to throw light on the factors contributing to the susceptibility of chromium-nickel austenitic heat-resisting steels (in particular, steels of 18-12-1Nb type) to cracking in the heat-affected zone of weldments.

In the initial phase of the study the B.W.R.A. cracking test was used to investigate cracking in 18-12-1Nb steel welds produced using the electrodes noted below:

C %	Mn %	Si %	Ni %	Cr %	Mo %	Nb %	Cu %	Co %	W %
0·09	1·2	0·46	9·2	18·8	—	0·7	2·0	—	—
0·3	2·0	0·6	15·0	17·0	3·0	2·0	—	7·0	—
—	—	—	—	33·0	—	—	—	55·0	6·0

Experiments were carried out (1) to study the occurrence of cracking during welding and post-weld heat-treatment, and (2) to gain information on the influence of weld-metal strength on cracking during post-weld heat-treatment (tests in the last connexion were conducted both on 18-12-1Nb and on 18-8 and 18-10-3Mo grades of steel). The heat-affected zones of the weldments were examined

by optical and electron microscopy. On the assumption that the microstructure developed in the heat-affected zone would be an important factor in cracking susceptibility, in the second phase of the test programme a metallographic survey was conducted on steels exposed to heat-treatments designed to produce microstructures simulating those of heat-affected zones: specimens of 18-12-1Nb steel were thermally cycled and heat-treated for 100 hours at 750°C., and specimens of 18-12-1Nb and 18-10-3Mo steels were thermally cycled, plastically deformed and then heat-treated at 750°C. The mechanism of cracking is discussed in the light of the results of these investigations.

It was found that, during welding, small hot tears (up to 0·03-in. in depth) usually formed (due to liquation in regions of high solute segregation) at the metal surface in the part of the heat-affected zone immediately adjacent to the weld. Extensive intergranular cracking occurred during heat-treatment after welding, the cracks initiating at hot tears which increased susceptibility to cracking by providing points of easy initiation.

The mechanism of crack formation during heat-treatment was quite distinct from that responsible for hot-tear formation. Intergranular cracking during re-heating after welding was always accompanied by the precipitation of a fine intragranular precipitate. (In 18-12-1Nb steel the precipitate was NbC; in unstabilized 18-8 steel it was $M_{23}C_6$; the steel containing molybdenum exhibited little or no intragranular precipitate and did not crack.) The formation of the fine intragranular precipitate was strain-induced, larger amounts of plastic strain producing more dislocations which served as nucleation sites and resulted in finer and more numerous precipitated particles. When the hot strength of the weld metal was increased, the extent of cracking also increased, and the intragranular precipitate was finer and more numerous.

Cracking during heat-treatment is attributed to stiffening of the grains, which results in intergranular fracture of a type similar to that observed during creep and hot tensile tests.

Influence of Welding on the Properties of Cold-Worked Austenitic Steel

L. STEMANN and E. E. WEISMANTEL: 'Weld Strength and Dimensional Stability of Cold-Worked Stainless Steel.'

Welding Jnl., 1960, vol. 39, Oct., pp. 438s–42s.

Cold-worked austenitic stainless steel offers attractive properties to the design engineer concerned with highly-stressed sheet-metal structures: exceptionally high strength associated with good ductility; excellent corrosion-resistance; lack of notch sensitivity; and adequate toughness at low and high temperatures. Since, however, the heat-affected zone of a weld is generally regarded as basically an annealed band, and since the yield strength of an annealed austenitic stainless steel is low, the use of design data based on the properties of the steel in the annealed condition has limited the value of the steel for structures fabricated by fusion welding. Data are, however, available which suggest that weldments of cold-worked stainless steels are capable of withstanding much higher stress levels than those based on properties in the annealed condition. The investigation now described was therefore undertaken to determine the influence of fusion welding on the properties of thin-gauge stainless steel in tempers ranging from ¼-hard to full-hard.

A.I.S.I. Type 301 18-8 chromium-nickel stainless steel was selected for study, and the tests were conducted on butt welds produced (using the tungsten-arc technique) in specimens 0·02–0·125 in. (0·25–3·125 mm.) thick. The properties of the weldment were evaluated by measuring the 0·2 per cent. off-set yield strength for a 2-in. (5-cm.) gauge length across the weld line, and also by determining the ultimate strength and the total elongation for the given gauge length. Tensile tests were conducted at room temperature, 400°F. and 700°F. (205° and 370°C.). To determine (1) the temperature at which relaxation would occur, (2) the relative amount of dimensional change resulting from exposure at different temperatures, and (3) the effect of temperature on the properties of the steel, unwelded basis-metal strips were measured, held for 1 hour at 700°, 1050° or 1200°F. (370°, 565° or 650°C.), remeasured, and then subjected to tensile tests.

The data derived from the research programme are recorded in tabular and graphical form.

Compared with the properties of unwelded specimens, the yield strength and ultimate strength of welded specimens were found, in all cases, to be lower, but the values obtained were nevertheless considerably higher than those for the annealed material. Tests to evaluate the effects of metal thickness on the mechanical strength of butt-welds showed that, in the case of ¼-hard and full-hard material, the 0·2 per cent. offset yield strength was lower for the heavier gauges studied. The ultimate strength did not, however, change appreciably with variation in gauge. The data for half-hard materials exhibited more scatter, and no general trends were apparent.

From the curve illustrating the yield strength of the butt welds as a function of the test temperature, it is considered that the effects of gauge thickness noted for ¼- and full-hard material were maintained at all test temperatures. In comparing these data on elevated-temperature properties with design-minimum curves for Type 301 stainless steel, the authors emphasize that, while the strength of butt welds is lower than that of the respective basis-metal design properties, the values were still considerably superior, at all test temperatures, to those of the annealed material.

Data recorded on the other phases of the test programme reveal that significant dimensional changes occurred in half-hard and full-hard material as a result of exposure to temperatures above 800°–900°F. (425°–480°C.), and that the room-temperature tensile and yield properties of the full-hard stainless steel decreased markedly after exposure to temperatures above 1050°F. (565°C.), an effect which, in combination with the dimensional changes, is

considered to warrant examination of the suitability of cold-worked Type 301 stainless steel for critical-stress applications involving even very short exposure to such temperatures.

Development of Nickel-base High-Temperature Brazing Alloys

W. LEHRER and H. SCHWARTZBART: 'Volatilization Phenomena in High-Temperature Brazing Filler Alloys.'

Welding Jnl., 1960, vol. 39, Oct., pp. 449s-61s.

The test programme reported in the present paper originated in work carried out, by CANONICO and SCHWARTZBART, on the development of brazing alloys resistant to oxidation and liquid sodium (see *W.A.D.C. Tech. Report* 57-648: abstract in *Nickel Bulletin*, 1958, vol. 31, No. 12, pp. 349-50). In that study, indium and lithium were added to nickel-, iron- and chromium-base alloys, as a means of depressing the brazing temperature and as aids to flow when used in a hydrogen atmosphere to produce 'Inconel'/stainless-steel brazements. Alloy compositions were developed which flowed at temperatures in the range 1750°-1900°F. (955°-1035°C.). Lithium-bearing nickel-chromium-germanium alloys withstood 500 hours' exposure to atmospheric oxidation at 1650°F. (900°C.), but the presence of appreciable amounts of indium resulted in loss of oxidation-resistance. It was recognized that advantage could still be taken of the desirable flow properties and the temperature-depressant effects associated with indium, provided that the element could be removed after flow had occurred (when oxidation-resistance should be that of the straight nickel-chromium-germanium alloys). As a corollary to restoring oxidation-resistance to the alloys, the removal of indium would necessarily result in an alloy of higher melting temperature, and, hence, in a corresponding increase in the high-temperature strength of the filler alloy. The development of such a brazing alloy (i.e., one which may be applied at a relatively low brazing temperature, but which would subsequently exhibit a much higher re-melt temperature) became the object of the research described.

The two main mechanisms by which compositional changes may occur in the filler alloy during a brazing cycle are: (*a*) metallurgical change due to solution of the basis metal and the selective diffusion of filler-alloy constituents into the basis metal, and (*b*) compositional changes due to volatilization of an alloying element. The fundamental metallurgical principles and the practical factors involved in the application of each of these two mechanisms to the removal of the temperature-depressant constituent of the brazing alloy are considered in the preamble of the paper. On the basis of these considerations, the authors selected four factors for investigation: (1) the effect of interdiffusion of filler and basis metal on the re-melt temperature in the absence of volatilization; (2) the effect of the volume of the brazing container on the re-melt temperature; (3) the relative effects of dynamic-vacuum and of infinite-volume static-helium atmospheres on the re-melt temperature; (4) the effects of the presence of metallic vapours on wetting and flow characteristics.

With the exception of the binary alloys, all the alloys studied were chosen on the basis of the results of the previous investigation. Compositions are reproduced in the table on p. 327. Each alloy contained a volatile constituent (gallium, indium, lithium, antimony or phosphorus). Brazing characteristics were evaluated by pre-placing the powdered alloys along one side of the capillary formed by a T-specimen of 18-8 stainless steel.

Full details are given of the test conditions and apparatus employed, and the results are presented and discussed *in extenso*.

On the basis of theoretical considerations and the experimental data, it is concluded that the re-melt temperature will increase (either by the dissolution-diffusion mechanism or volatilization) only if the diffusing or volatilizing element exhibits some solid solubility in the filler alloy. Secondly, although composition changes may result from the operation of either mechanism, a change in re-melt temperature (solidus temperature) does not necessarily occur. The degree to which a compositional change affects the re-melt temperature by either mechanism is proportional to the solid solubility.

In the present programme, vacuum pumping proved the most efficient vapour-removal method of the several discussed and investigated. The method also has the advantage that, *in vacuo*, the surface-area/volume ratio of the filler alloy becomes, due to boiling, less rate-controlling (boiling, however, causes porosity in the joint).

Assessed on the basis of volatilization alone, the indium-bearing nickel-base alloys showed the most promise. Of these alloys, alloy A (solidus temperature 1675°F.: 913°C.) exhibited the greatest rise in re-melt temperature, as well as the highest re-melt temperature. This alloy is considered worthy of study as a practical alloy for high-temperature usage (it is presumed that chromium could be added to impart oxidation-resistance without affecting its melting characteristics). In terms of rise in re-melt temperature due to dissolution of the basis metal and diffusion into the basis metal, the alloys yielding the greatest rise in re-melt temperature in the absence of volatilization were alloy M and the nickel-indium-chromium-germanium quaternaries. Alloy K exhibited the smallest rise in re-melt temperature. The differences in the behaviour of the nickel-phosphorus and iron-phosphorus binaries is explained on the basis of phase diagrams and diffusion rates.

In discussing the data obtained from the practical brazing experiments (which were carried out either *in vacuo*, in helium followed by evacuation, or in helium at 5 p.s.i.g.), the authors draw attention to the properties offered by alloy N. This alloy exhibited a low solidus temperature 1750°F. (955°C.), an apparently low liquidus temperature (as indicated by the small skull formation even at a brazing temperature of 1820°F. (900°C.)), and flowed and wetted well under all conditions. Its rise in re-melt temperature

Composition of Brazing Alloys

(*See abstract on p. 326*)

Alloy	Composition %										Solidus Temperature		Remarks
	Ni	Cr	Fe	In	Li	Sb	Si	Ge	P	Ga	°F.	°C.	
A	61	—	—	39	—	—	—	—	—	—	1675±10	913±6	—
B	—	—	48	—	—	52	—	—	—	—	1825±10	996±6	Eliminated—formed brittle joints.
C	64·4	17	—	9·2	—	—	9·2	—	—	—	1885±10	1029±6	—
D	33·3	33·3	—	16·7	—	—	16·7	—	—	—	—	—	Eliminated—non-homogeneous and erratic in m.p.
E	38·1	28·6	—	—	4·7	—	—	28·6	—	—	—	—	Eliminated—lithium separated as 2nd liquid phase.
F	38·1	28·6	—	4·7	—	—	—	28·6	—	—	1885±10	1029±6	—
G	28·6	19·1	—	—	4·7	—	—	47·6	—	—	1880±10	1025±6	—
H	30·8	30·8	—	23	—	—	—	15·4	—	—	1890±10	1030±6	—
I	33·3	33·3	—	16·6	—	—	—	16·6	—	—	1885±10	1029±6	—
J	89	—	—	—	—	—	—	—	11	—	—	—	Eliminated in favour of alloy M.
K	—	—	89·5	—	—	—	—	—	10·5	—	1900±10	1035±6	—
L	64·9	—	—	—	—	—	—	—	—	35·1	—	—	Eliminated—was not homogeneous after successive arc melts
M	94	—	—	—	—	—	—	—	6	—	1600±10	870±6	—
N	35	24	—	26	—	—	—	15	—	—	1750±10	955±6	—

was consistently high (at a temperature of 1820°F., however, vacuum brazing yielded higher re-melt temperatures than helium brazing).

The presence of metallic vapours was found to influence the wetting and flow characteristics: the influence of these vapours on surface-tension relationships is discussed in this connexion. It is demonstrated that, in the presence of metal vapours, discoloration of the basis metal, and wetting, flow and skull formation of the filler alloy, are functions of the rate and degree of metal-vapour removal.

Determination of Titanium in High-Temperature Alloys

N. M. SILVERSTONE and B. B. BACH: 'Spectrophotometric Determination of Titanium in High-Temperature Alloys.'

Metallurgia, 1960, vol. 62, Aug., pp. 81–2.

Titanium may be determined gravimetrically as the oxide, after precipitation and ignition of the hydroxide or cupferrate, or colorimetrically, as the peroxy-complex or cupferrate. These methods are all subject to interference from other constituents of high-temperature alloys, or the colours are unstable. The method in general use involves addition of hydrogen peroxide to an acid solution of the alloy, and measurement of the optical density of the yellow-orange colour produced by the titanium and molybdenum with subsequent correction for the molybdenum. This method presupposes accurate determination of the molybdenum, and the preparation of correction calibrations. The work now described was carried out to satisfy requests for an alternative accurate method in which molybdenum would not interfere.

In the procedure finally evolved, the titanium is separated as hydroxide, and interference due to molybdenum, chromium and iron is eliminated. After dissolution of the hydroxide, hydrogen peroxide is added, and the optical density of the solution is determined spectrophotometrically. Data derived from determinations of titanium in 'Nimonic 100' reveal the method to be accurate and to give good reproducibility over the range 1–2 per cent. titanium.

ANALYSIS

Analysis of Ultra-Pure Nickel

See abstract on p. 299.

Determination of Titanium in High-Temperature Alloys

See abstract in left-hand column.

Attention is drawn to the fact that many of the names of materials mentioned in The Nickel Bulletin are *Trade Marks*.

Corrigendum

Nickel Bulletin, 1960, vol. 33, No. 10, p. 244.

Right-hand column, **'Hardenability Effect of Boron on Steel'**, line 1.

For R. A. ORANGE,

read R. A. GRANGE.

A Publication prepared by the
DEVELOPMENT AND RESEARCH DEPARTMENT
of
THE MOND NICKEL COMPANY LTD.

PRINTED IN ENGLAND BY WIGHTMAN MOUNTAIN LTD.
WESTMINSTER, LONDON, S.W.1

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Properties and Applications of '17-4 P.H.' Steel, pp. 19-20, last paragraph, first line.
For '17-7 P.H.'
Read '17-4 P.H.'

Corrosion of Nickel and 'Inconel' in a Fused-Salt Environment, p. 28.
For W. D. MANLY
Read D. H. JANSEN.
For *U.S. Atomic Energy Commission, Report ORNL* 57-6-72, 1959; 8 pp.,
Read *U.S. Atomic Energy Commission, Report ORNL* 57-6-72, 1957; 8 pp.

Chemical Deposition of Nickel-Boron and Cobalt-Boron Alloys, p. 34.
For *French Pat.* 1,977,797
Read *French Pat.* 1,197,797.

Nickel Bulletin, 1960, vol. 33, No. 10, p. 244.

Hardenability Effect of Boron on Steel, line 1.
For R. A. ORANGE
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Nickel Bulletin, 1960, vol. 33, No. 12, p. 307.

Influence of Double Tempering on the Life of 'Ni-Hard' Grinding Balls, line 3.
For *Engineering*, 1960, vol. 190, No. 4, pp. 598-9
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A Publication prepared by the

DEVELOPMENT AND RESEARCH DEPARTMENT

of

THE MOND NICKEL COMPANY LTD.

PRINTED IN ENGLAND *by* WIGHTMAN MOUNTAIN LTD.
WESTMINSTER, LONDON, S.W.I